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FINAL REPORT 43U-629-1

STUDY OF AIR DISTRIBUTION IN LARGE SINGLE-ROOM SHELTERS

by

M.D. Wright, E.L. Hill & D.R. Whitaker

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RESEARCH TRIANGLE PARK, NORTH CAROLINA 27709

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13. ABSTRACT

This report describes experimental studies performed to determine the effect of OCD-developed, manually powered ventilation equipment for ventilating large, single-room shelters and to evaluate the maximum size facility that can be ventilated with this equipment. The equipment used consisted of a 30-inch fan and an air distributional device called a Kearny pump. The equipment was operated using various configurations of apertures for air inlet and exhaust. During each test, airflow rate measurements were taken at heights of three feet and six feet above floor level using hot wire anemometers at measurement points marked off on the floor of the test facility. These measurements were used to develop iso-speed contours for airflow rates of 20 fpm and 40 fpm over the floor of the test facility. In those tests where significant portions of the floor area had airflow rates of less than 20 fpm using the fans alone, Kearny pumps were used to improve the distribution of air over the floor area.

From these tests it was concluded that the manually powered equipment can be used to effectively ventilate large, single-room shelters for most of the aperture configurations investigated. In the optimum configuration, 100 percent of the floor area had an airflow rate of 20 fpm or more. In the other configurations, the percent of floor area having an airflow rate of 20 fpm or more ranged from 19 percent to 98 percent.

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DETACHABLE SUMMARY

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Study of Air Distribution in Large Single-Room Shelters

by

M. D. Wright, E. L. Hill and D. R. Whitaker

for

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
Washington, D. C. 20310

under

Contract No. DAHC20-71-C-0275
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Study of Air Distribution in Large Single-Room Shelters

I. INTRODUCTION

It is estimated that more than 50 million fallout shelter spaces could be added to the National Fallout Shelter Survey (NFSS) inventory by providing additional ventilation to those shelter areas where existing ventilation does not meet specified standards. In an effort to acquire these additional spaces, the Office of Civil Defense (OCD) sponsored the development of manually powered equipment to supply and distribute additional air in shelters. This equipment consists of a 30-inch diameter fan and a Kearny pump, which is an oscillating uni-directional air pump consisting of a series of overlapping flap valves stretched across a frame which is hinged at the top.

Studies by the Protective Structures Development Center and by General American Transportation Corporation have demonstrated that the manually powered equipment is effective in supplying and distributing air in small to moderate size shelters (780 to 4,000 sq. ft.). A previous RTI analysis of NFSS data for shelters requiring ventilation improvements indicates that larger shelter areas may be of greater significance, with approximately 45 percent of all spaces contained in shelter stories having 1,000 or more spaces (10,000 or more square feet of total area).

The objectives of this research effort were: (a) to evaluate the effectiveness of this equipment in supplying and distributing air in large open shelters with various configurations of exterior apertures, (b) to determine the largest shelter which can be ventilated using the equipment, (c) to develop the most cost-effective systems of ventilating and distributing air in large shelters, and (d) to determine those system parameters which significantly influence system performance.

II. TEST PROCEDURES

The work involved operating the OCD-developed ventilation equipment in a large open building, with plan dimensions of 80 feet by 322 feet. Hot-wire anemometers were used to measure the airflow rate at predetermined locations. The measurements were used to develop iso-speed contours to delineate those portions of the floor area having an established minimum air movement. For the purpose of these tests, the minimum was set at 20 feet per minute (fpm); however, the iso-speed contours for 40 fpm were also identified.

Twenty-nine ventilation tests were performed using twelve configurations of air inlet and exhaust apertures.

III. RESULTS AND CONCLUSIONS

Table 1 summarizes the results obtained from each of the ventilation tests performed. This table presents the percent of the floor area having airflow rates of 20 fpm and 40 fpm for each test and gives information on outside wind conditions, volume of air passing through the shelter, and the equipment used.

On the basis of the experimental results, the following conclusions and recommendations are made.

a) Effective duct length is the single most important item affecting system efficiency and should be kept to a minimum.

b) The effect of clustered PVKs versus having them separated needs further investigation.

c) The cross-sectional area of the path of airflow through a shelter should be kept to a minimum.

d) Using the recommended number of PVKs, a building the size of the test facility does not have adequate air movement in the 5 cfm zone; however, it does have adequate air movement in higher cfm zones provided widely separated apertures are available.

e) The measured volume of air delivered during the tests deviated from that predicted by the PVK performance curves because of air leaking into the building from sources other than the inlet apertures and variations in outside wind conditions.

f) Orientation of air inlet apertures has very little effect on system performance provided they are remote from the exhaust apertures.

g) Variations in the density of the air passing through a shelter, which is related to outside temperature, causes variations in the airflow rates at the 3-foot level.

h) Kearny pumps are effective in moving air up to 50 to 60 feet outside the normal path of airflow through a shelter.

i) The effectiveness of Kearny pumps in distributing air in a shelter is much greater if the orientation of the Kearny pumps is such that they move air in the same direction as the main path of airflow through the shelter.

j) Kearny pumps have a greater effect on airflow rates at the 3-foot level than at the 6-foot level.

k) During the tests using 10 fans, the percent of the floor area having an airflow rate of 20 fpm or more ranged from 19 percent to 100 percent.

l) It is desirable to know the aperture locations in a shelter in order to apply the information obtained from these tests.

Table 1

SUMMARY OF VENTILATION TEST RESULTS

Configuration	Test Number	Equipment Used (Number)		PVK Location	Effective Duct Length (feet)	Inlet Aperture Location	Outside Wind		Measured Volume of Air Delivered (cfm)	3-FOOT LEVEL Percent of Floor Area Having		6-FOOT LEVEL Percent of Floor Area Having	
		PVKs	Kearny Pumps				Direction	Speed (fpm/mph)		≥20 fpm	≥40 fpm	≥20 fpm	≥40 fpm
A	1A	10	0	North Side (Windows)	1,000	South Side	SW	75/.85	17,000	21	4	29	4
A	1B	10	4	North Side (Windows)	1,000	South Side	SW	75/.85	17,000	27	11	23	3
B	2A	10	0	NW Half (Windows)	1,000	W-4 Doors	W	195/2.2	15,000	48	15	26	12
B	2B	10	4	NW Half (Windows)	1,000	West End	SW	440/5.0	15,500	37	15	27	14
B	2C	10	4	NW Half (Windows)	1,000	West End	SW	85/.95	21,000	43	16	36	9
B	2D	10	0	NW Half (Windows)	1,000	W-2 Doors	N	325/3.7	18,000	32	9	18	5
C	10A	10	0	NE Corner (Windows)	1,000	West End	SW	120/1.4	30,000	93	66	86	54
C	10B	10	4	NE Corner (Windows)	1,000	West End	SW	315/3.6	34,500	100 1/	84 1/	98 1/	60 1/
D	11A	10	0	NE Corner (Windows)	1,000	SW Corner	SW	220/2.5	22,000	90	6[illegible]	92	29
D	11B	10	2	NE Corner (Windows)	1,000	SW Corner	SW	220/2.5	22,000	100	95	100	57
E	12	10	0	NE Corner (Windows)	1,000	NW Corner	NE	265/3.0	27,500	96	43	81	23
F	13	10	3	NE Corner (Windows)	1,000	SE Half	E	180/2.0	22,000	69	20	80	25
G	14	10	3	NE Half (Windows)	1,000	SE Half	ENE	430/4.9	15,000	19	7	27	5
H	3A	10	0	East End (Doors)	8	West End	SW	210/2.4	37,000	83	30	94	59
H	3B	10	4	East End (Doors)	8	West End	SW	300/3.4	40,000	89	48	94	30
H	7	8	0	East End (Doors)	8	West End	WNW	240/2.7	40,000	93	69	88	57
H	9A	6	0	East End (Doors)	8	West End	SW	230/2.6	26,000	86	2/	86	2/
H	9B	4	0	East End (Doors)	8	West End	SW	355/4.0	23,500	25	2/	53	2/
H	9C	2	0	East End (Doors)	8	West End	SW	350/4.0	21,500	18	2/	29	2/
H	9D	3/	-	--	--	West End	SW	220/2.5	14,500	10	2/	12	2/
H	9E	4/	-	--	--	West End	SSW	275/3.1	10,500	75	2/	87	2/
I	4A1	10	0	East End (Doors)	14	SW Corner	NNE	275/3.1	28,000	96	66	90	40
I	4A2	10	0	East End (Doors)	8	SW Corner	NE	200/2.3	28,000	97	59	97	67
I	4B	10	4	East End (Doors)	14	SW Corner	NNE	275/3.1	28,000	97	84	98	68
J	5	10	0	East End (Doors)	8	NW & SW Corners	SW	65/.74	32,000	94	57	97	68
K	6	10	0	East End (Doors)	8	NW Corner	SW	175/2.0	26,500	76	53	84	64
L	8A	10	3	East End (Doors)	8	Mid. N & S Sides	W	30/.35	23,500	35	17	45	23
L	8B	10	4	East End (Doors)	8	Mid. N & S Sides	SW	220/[illegible]	29,500	45	22	53	25
L	8C	10	0	East End	8	Mid. N & S Sides	SSE	100/1.1	29,500	55	30	63	45

1/ Readings were taken only in the areas which previously had low airflow rates; these were eliminated by the Kearny pumps.

2/ The area having an airflow rate of 40 fpm or more in the tests with 6 or less fans was quite small and, consequently, the areas were not computed.

3/ In this test, the 10 PVKs were in place in the doors in the east end of the building but were not turned on.

4/ In this test, no equipment was present in the building and the doors in each end of the building were open.

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This report describes experimental studies performed to determine the effect of OCD-developed, manually powered ventilation equipment for ventilating large, single-room shelters and to evaluate the maximum size facility that can be ventilated with this equipment. The equipment used consisted of a 30-inch fan and an air distributional device called a Kearny pump. The equipment was operated using various configurations of apertures for air inlet and exhaust. During each test, airflow rate measurements were taken at heights of three feet and six feet above floor level using hot wire anemometers at measurement points marked off on the floor of the test facility. These measurements were used to develop iso-speed contours for airflow rates of 20 fpm and 40 fpm over the floor of the test facility. In those tests where significant portions of the floor area had airflow rates of less than 20 fpm using the fans alone, Kearny pumps were used to improve the distribution of air over the floor area.

From these tests it was concluded that the manually powered equipment can be used to effectively ventilate large, single-room shelters for most of the aperture configurations investigated. In the optimum configuration, 100 percent of the floor area had an airflow rate of 20 fpm or more. In the other configurations, the percent of floor area having an airflow rate of 20 fpm or more ranged from 19 percent to 98 percent.

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I. INTRODUCTION

Significant numbers of fallout shelter spaces could be added to the National Fallout Shelter Survey (NFSS) inventory by providing additional ventilation to those shelter areas where existing ventilation does not meet the standards specified in ER-1190-1-2 [Ref. 1]. In 1965, it was estimated that approximately 50 million spaces were in this category [Ref. 2]. In an effort to acquire these additional spaces, the Office of Civil Defense (OCD) sponsored the development of manually powered equipment to supply and distribute additional air in shelters. This equipment consists of a 30-inch diameter fan and a Kearny pump, which is an oscillating uni-directional air pump consisting of a series of overlapping flap valves stretched across a frame which is hinged at the top.

Studies by the Protective Structures Development Center [Ref. 3] and by General American Transportation Corporation [Ref. 4] have demonstrated that the manual equipment is effective in supplying and distributing air in small to moderate size shelters (780 to 4,000 sq. ft.). A previous RTI analysis of NFSS data for shelters requiring ventilation improvements indicates that larger shelter areas may be of greater significance. For example, approximately 45 percent of all spaces are contained in shelter <u>stories</u> having 1,000 or more spaces (10,000 or more square feet of total area) [Ref. 2].

The objectives of the research described herein have been: (a) to evaluate the effectiveness of the manual equipment in supplying and distributing air in <u>large</u> open shelters with various configurations of exterior apertures, (b) to determine the largest shelter which can be ventilated using the equipment, (c) to develop the most cost-effective systems of ventilating and distributing air in large shelters, and (d) to determine those system parameters which significantly influence system performance.

The work involved the operation of the OCD-developed ventilation equipment in a large open building, measuring the airflow rate at predetermined locations, and developing iso-speed contours to delineate those portions of the floor area having a minimum air movement. For the purpose of these tests, the minimum was set at 20 feet per minute (fpm); however, the iso-speed contours for 40 fpm were also identified.

II. TEST PROCEDURES

A. Test Facility

The facility utilized in this ventilation study is located on the North Carolina State Fairgrounds in Raleigh, North Carolina. The building has plan dimensions of 323 feet by 80 feet and is situated such that the long dimension runs in an east-west direction. The ceiling height for the western half of the building averages approximately 15 feet and 18 feet for the eastern half. The floor plan and cross-sectional views of the test facility are shown in Figure 1 and exterior views are shown in Figure 2.

During the ventilation tests, the building was empty except for minor permanent structures; including a display booth and a produce display rack, which are shown in Figure 3. Although these structures had an influence on the airflow patterns in the building, they did not interfere with obtaining the objectives of the research.

There are windows along both the north and south sides of the building. In the western half of the building, the windows are 2 feet wide by 3 feet high and are 10 feet 2 inches above the floor. These windows are arranged in groups of three, as shown in Figure 4, with 8-inch dividers between the windows in each group and a 3-foot 9-inch wall section between groups. In the eastern half of the building, the windows, shown also in Figure 4, are 2 feet wide by 4 feet high and are 11 feet 4 inches above the floor. These windows are also arranged in groups of three similar to those in the western half.

There are two doors, 8 feet 5 inches wide by 9 feet 10 inches high, in the east end of the building and there are four doors, 3 feet 6 inches wide by 7 feet 7 inches high, in the west end of the building as shown in Figure 1. There are also large openings in approximately the center of both the north and south walls; however, these were covered with plastic and sealed throughout the testing.

B. Ventilation Equipment

Ten fan units and four Kearny pumps were assembled for use in these ventilation tests. The specifications for the standard Packaged Ventilation Kit (PVK) call for a special bell-shaped shroud; however, due to the expense of having special shrouds manufactured, the fan units were assembled using shrouds from an off-the-shelf 30-inch diameter fan. The shroud was bell-shaped with the bell radius slightly less than the radius of the specified shroud. Information provided by OCD [Ref. 5] indicates that the shroud used should produce results essentially the same as the specified shroud. The PVKs, shown in Figure 5, used the fan blade identified in the specifications. They were also powered with one-sixth horsepower electric motors and were geared to run at a speed of approximately 480 rpm, which is the normal operating speed of the manually powered units.

The Kearny pumps (Figure 6) were assembled in accordance with OCD specifications except that the entire frame was built as a single unit rather than in two pieces and different hinges were used. The Kearny pumps were electrically driven at approximately 28 cycles per minute, which is the normal rate of operation when manually powered. The drive mechanism consisted of a one-tenth horsepower gearmotor mounted on a wooden frame. An 18-inch level arm was attached to the output shaft of the gearmotor. A rope was fastened to the lever arm, passed through a pulley, and then fastened to the Kearny pump. First attempts to drive the Kearny pump using this arrangement produced a rather severe shock on the drive mechanism due to the fact that the pump could not complete its backswing before the gearmotor began the next forward swing. To alleviate this condition, a spring was incorporated into the drive to absorb the shock. During the ventilation tests, the Kearny pumps were driven to swing through an arc of approximately 63°, which was established by previous researchers [Ref. 4] as a comfortable arc for manual operation.

The A-frames on which the Kearny pumps were mounted were constructed of standard electrical conduit fastened together with standard connectors called by the trade name "Kee-Klamps."

C. Measuring Equipment

The instruments used to measure the airflow rate during the ventilation tests were two Alnor Instrument Company Type 8500K thermo-anemometers. These devices utilize a platinum wire of small diameter as the sensor element, which is inserted in the airstream and heated by an electrical current. The amount of heat dissipated is measured and correlated with the speed of air movement. The instruments have scales of 10-300 fpm and 100-2,000 fpm, with published accuracies of ± 2 fpm on the low scale and ± 5 percent of the reading on the high scale.

The two anemometers were mounted on a wooden stand with wheels which permitted easy movement from one measuring point to another. The anemometer probes were fastened to the stand at heights of 3 feet and 6 feet above floor level as illustrated in Figure 7.

D. Equipment Tests

Since the fan shrouds used in these tests deviated slightly from OCD specifications, a capacity test was made to determine if their operating characteristics were significantly different from the published performance curves for the PVKs. The test of a fan unit was made by exhausting air from a single room and measuring the volume of air coming into the room through an open doorway, as shown in Figure 8. The results for two separate tests were 4,972 cfm and 4,910 cfm, which concurs with the PVK performance data given in Figures 2-10 of Reference 6.

A similar calibration was attempted for a Kearny pump; however, a suitable location was not available for conducting such a test. The only location available had five single standard size doorways along the path of airflow, as shown in Figure 9. A test was made in this location with measurements made at both the inlet and outlet doors. The results were substantially below the predicted capacity, which is reasonable since the performance of Kearny pumps is such that a very small increase in pressure head significantly reduces the volume of air delivered. The lack of a valid test for the Kearny pumps was not felt to be detrimental to the ventilation tests since these units were constructed in accordance with the specifications.

E. Building Preparation

Prior to performing any ventilation tests, all exterior openings in the test facility which were not expected to be used in the tests were sealed by covering them with polyethylene and/or taping around them. Points on the floor at which airflow rate measurements were to be taken during the ventilation tests were measured off and marked with chalk. These points were located on 10-foot centers in each direction, giving a total of 297 measurement points (including those within the display booth and produce display rack).

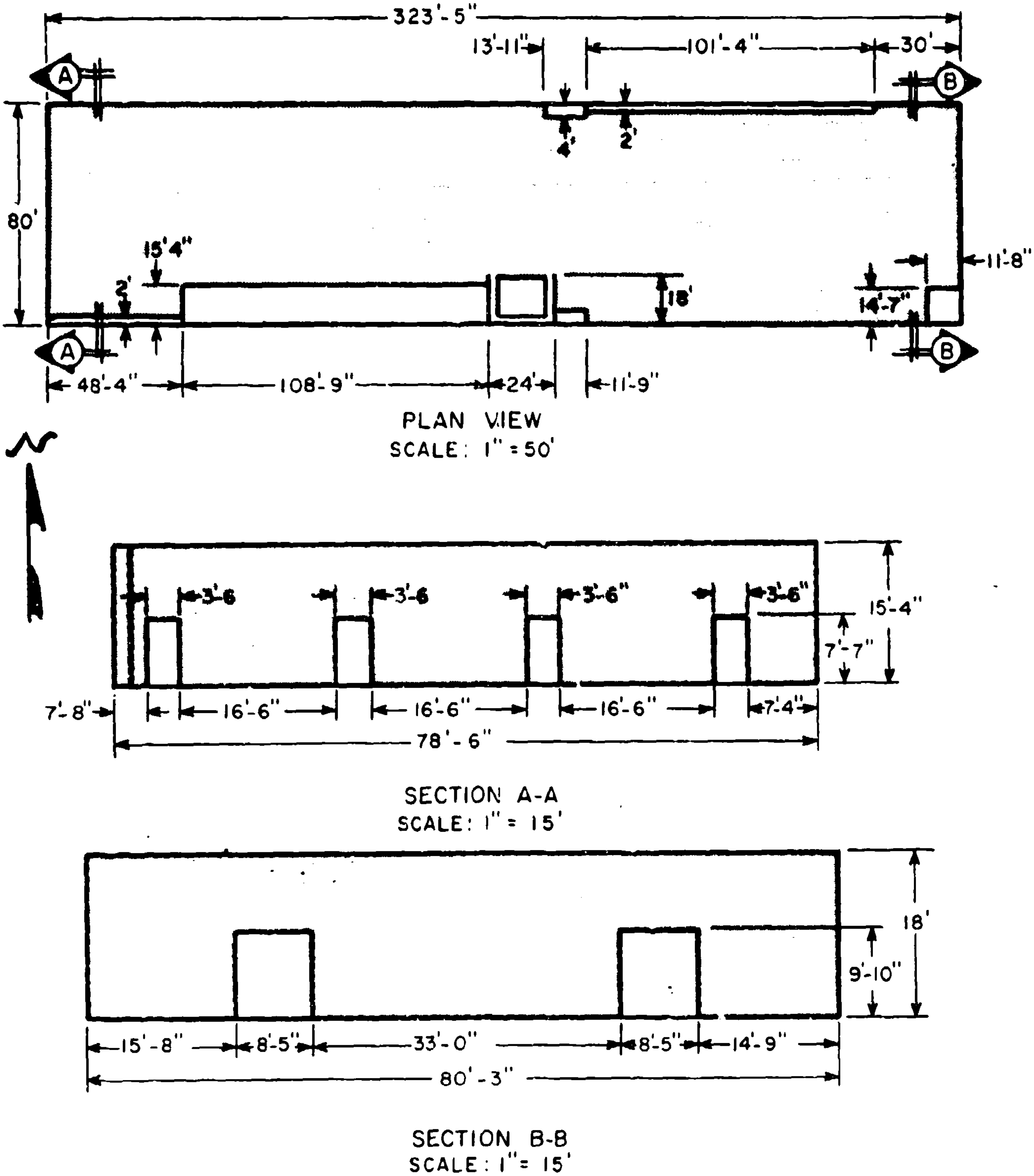
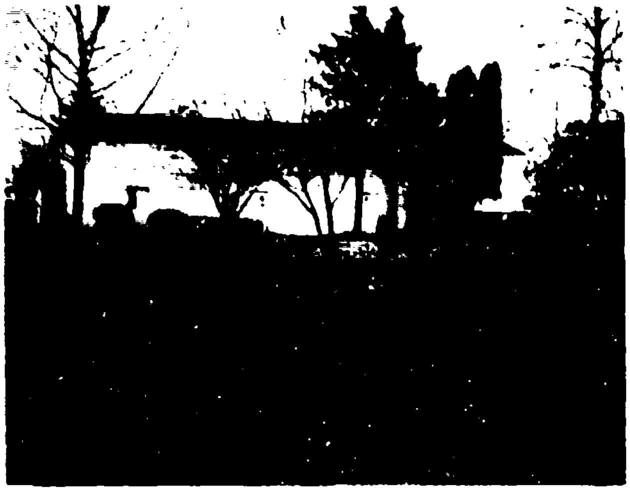
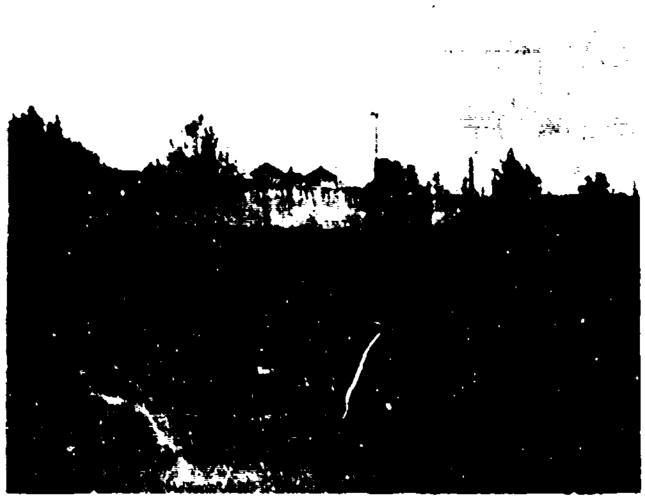


Fig. 1. Plan and Section Views of Test Facility.



a. West End.



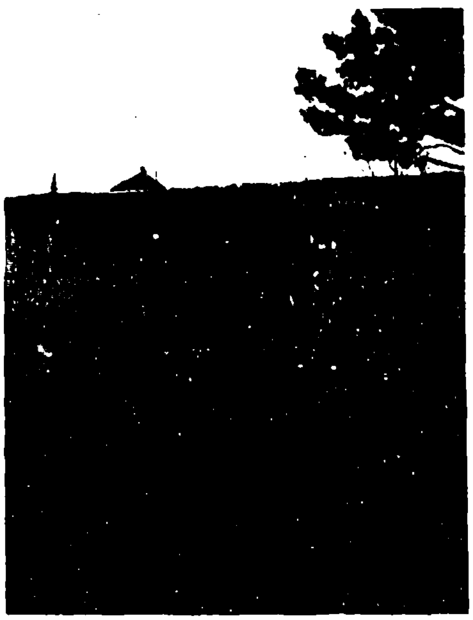
b. North Side.

c. East End.

d. South Side.

Fig. 2. Exterior Views of Test Facility.

Fig. 3. Permanent Structures in Test Facility.



a. West End (2-Foot by 3-Foot Windows).

b. East End (2-Foot by 4-Foot Windows).

Fig. 4. View of Windows in North Wall of Test Facility (Windows in the South Wall Are Identical).

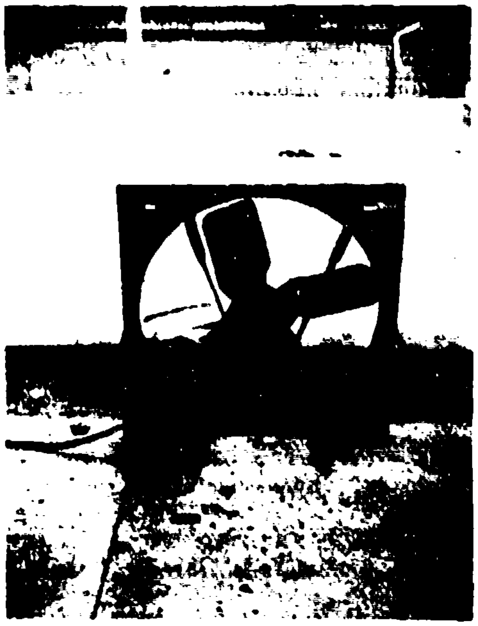


Fig. 5. Packaged Ventilation Kit (PVK).

Fig. 6. Kearny Pump.

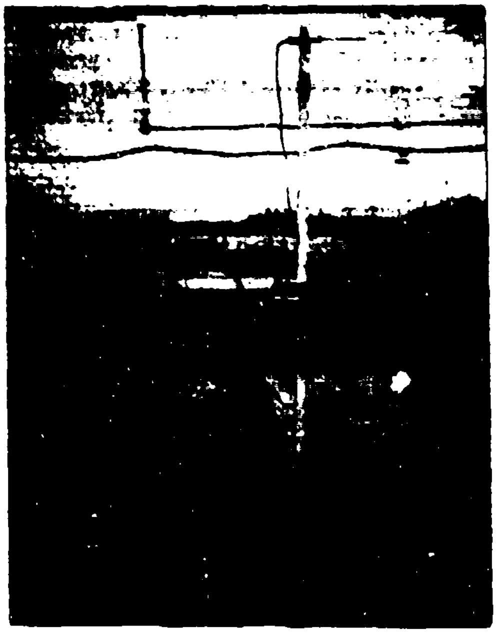


Fig. 7. Anemometer Stand with Anemometer Probes Located at 3-Foot and 6-Foot Levels.

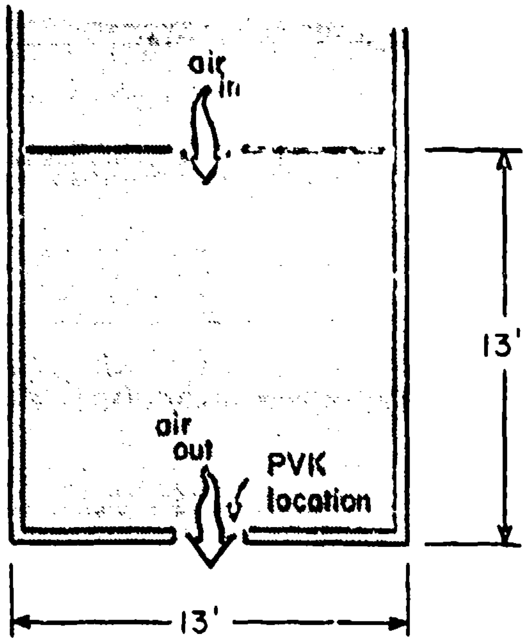


Fig. 8. PVK Test Configuration.

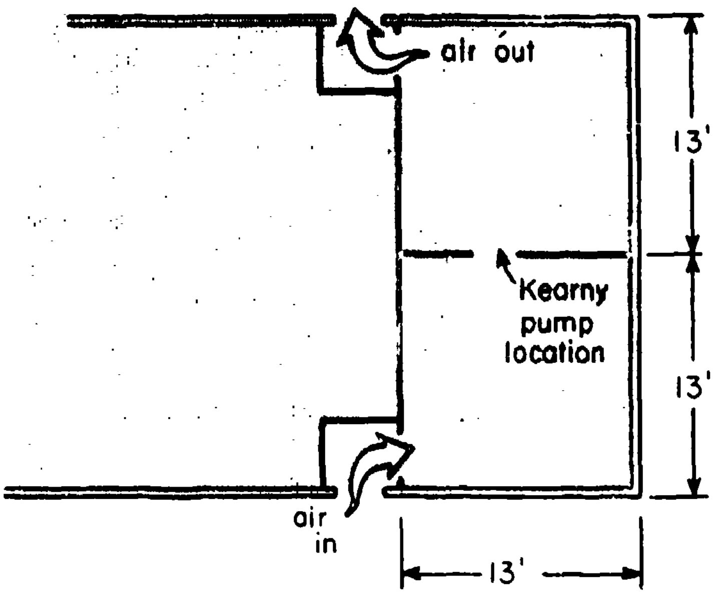


Fig. 9. Kearny Pump Test Configuration.

III. TEST RESULTS

During the course of this research, ventilation tests were performed using the 12 different combinations of ventilator location and air supply openings illustrated in Figure 10. Seven of these configurations employed plastic ducting, which was attached to the fan units and passed through windows approximately 10 feet above floor level. Although the actual duct length used with each fan was only about 25 feet, the effective duct length* for the tests was approximately 1,000 feet. The remaining five configurations had the fans exhausting air through doorways located in one end of the building. Plastic ducting was also employed in these configurations but the effective duct lengths were quite short; in the order of 3 feet to 10 feet.

Ten PVKs were assembled by RTI for use in these tests. For a shelter the size of the test facility (25,760 square feet), 10 PVKs would be allocated based on a 1,000-foot effective duct length and a ventilation rate of 7.5 cfm per shelter occupant (10 square feet). Consequently, those tests performed using the long ducts (Configurations A through G) are applicable to the 7.5 cfm zone. In the 15 cfm zone, 10 PVKs would be allocated to a shelter the size of the test facility on the basis of using a zero duct length. Therefore, those tests performed with the short ducts (Configurations H through L) are applicable to the 15 cfm zone, except for those tests in Configuration H using less than 10 fans.

During each test, measurements of the airflow rate were made at each of the 297 points marked off on the floor (except for the 30 covered by the permanent structure along the south wall). The measurements were made and recorded for heights of 3 feet and 6 feet above floor level. In most of the tests, measurements were made first using only the PVKs to supply air into the building. Following this, the Kearny pumps were placed and operated to direct air into any stagnant areas and the measurements were repeated. Although the direction of airflow was not recorded and used, it was necessary to determine the direction due to the directional response properties of the anemometer probes. In many cases, the direction in which air was moving was not easily discernible at some of the measurement points. In these cases, light smoke was used to make this determination.

In measuring the airflow rate at points located in the vicinity of the air inlet apertures, large fluctuations in the indicated speed were

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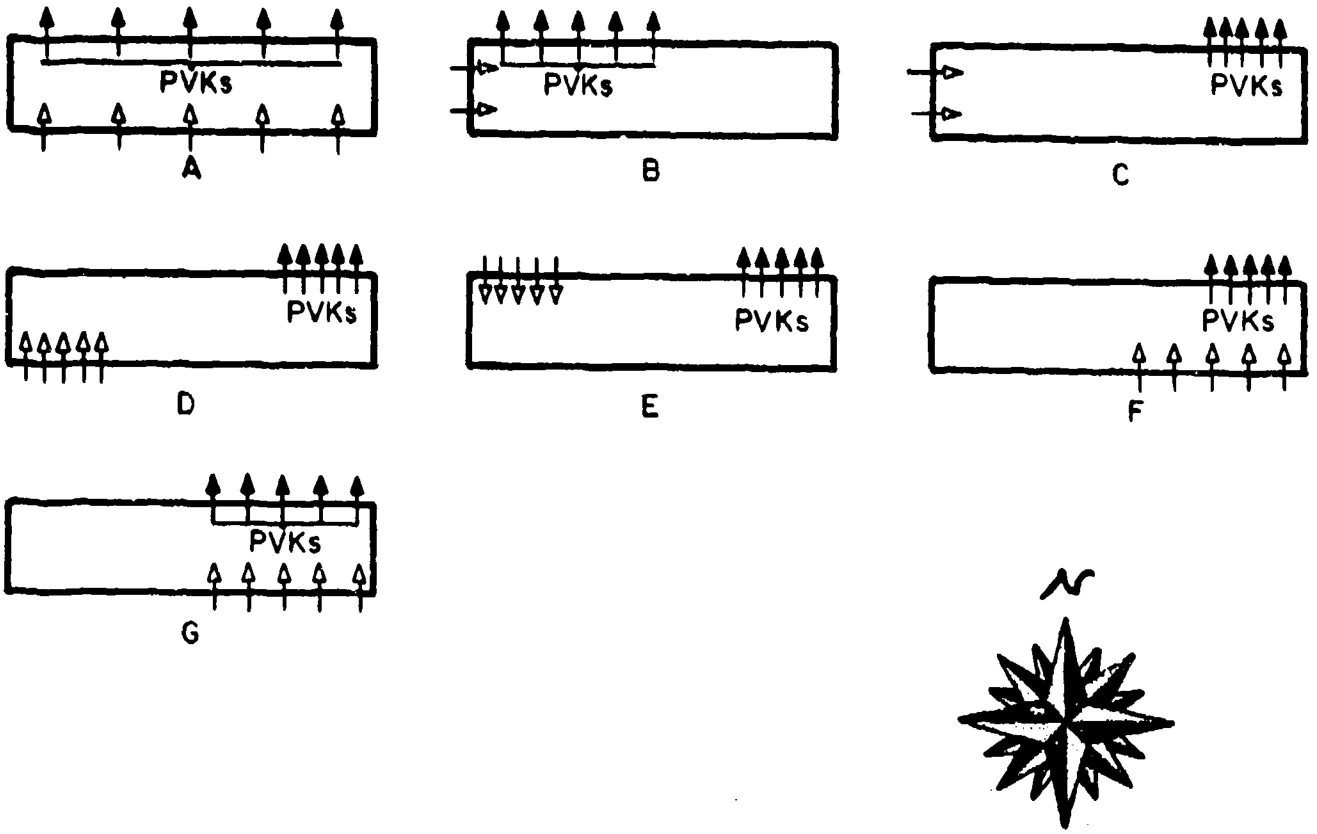
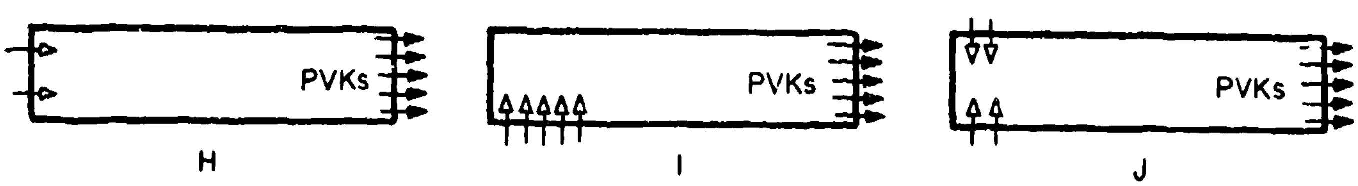
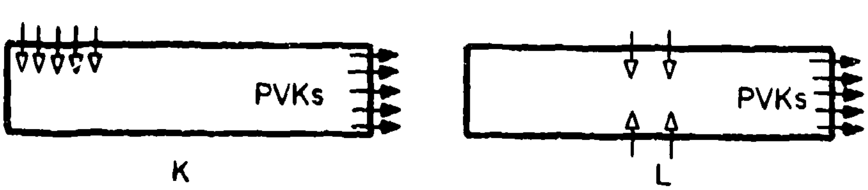
* Effective duct length is the actual length of duct plus the straight duct equivalent, in terms of pressure drop, of all bends in the actual duct.

a. Long PVK Effective Duct Lengths (1000 feet).



b. Short PVK Effective Duct Lengths (3 to 10 feet).





Note: PVK locations are shown by dark arrows; air inlet apertures are located by open arrows.

Fig. 10. Ventilator (PVK) and Aperture Configurations for Ventilation Tests.

observed. In these cases, the indicated speeds were observed for a minute or more and an average value based on the judgment of the experimentor was recorded. At measurement points farther away from the air inlet apertures and near the exhaust fans these fluctuations were not encountered.

Other data gathered for each test included the speed of the air passing through the air inlet apertures and the speed and direction of air movement outside the building. The prevailing winds for the Raleigh, North Carolina geographic area are southwesterly and, consequently, the exhaust fans for all tests were placed in either the eastern or northern walls in an effort to avoid exhausting air against the wind. This was not always successful because of occasional shifts in the wind direction to northeasterly or northwesterly.

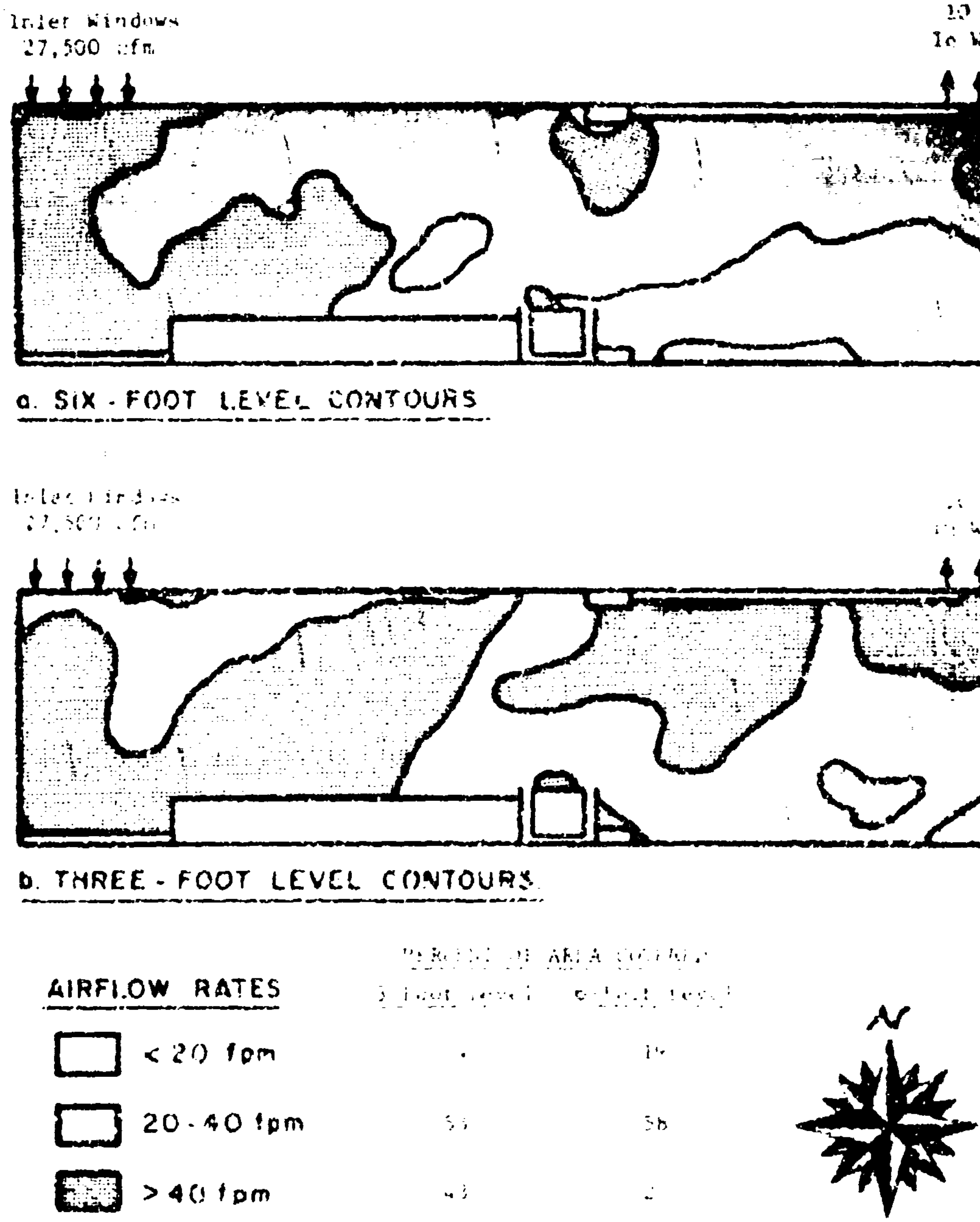
The data obtained from each ventilation test were utilized to develop iso-speed contour lines to define those areas of the building having measured airflow rates of less than 20 fpm, 20-40 fpm, and greater than 40 fpm. This is illustrated in Figure 11 for test 12 (Configuration E). These contour lines were developed for both the 3-foot and 6-foot level measurements and for the measurements taken both without and with the Kearny pumps in operation. Contour lines for all tests are contained in Appendix A.

The results for each test are given in summary form in Table 1.

Configuration A

In Configuration A, the 10 PVKs were evenly spaced along the north wall of the test facility. Polyethylene ducts were attached to each unit and passed through open windows 10 feet above the floor. Ten evenly spaced windows on the south wall were opened to permit air to enter. These windows were also 10 feet above the floor. The percentage of the floor area having measured airflow rates of 20 fpm or more in this configuration was 21 percent at the 3-foot level and 29 percent at the 6-foot level. Adding Kearny pumps improved the flow of air in the immediate vicinity of the pumps at the 3-foot level and increased the 20+ fpm area to 27 percent of the total floor area. However, this was at the detriment of the 6-foot level where the area was reduced to 23 percent.

Two factors contributed to the low readings: (a) the long effective duct length (1,000 feet) severely restricted the volume of air delivered by the fans, as can be seen in Table 1, and (b) the cross-sectional area of the airflow path in this configuration is very large relative to the volume of air moving through the shelter.



Outside Wind: [illegible]

Fig. [illegible]. Example [illegible] Airflow Rate Contours
([illegible] Number [illegible])

Table 1

SUMMARY OF VENTILATION TEST RESULTS

Configuration	Test Number	Equipment Used (Number): PVKs	Equipment Used (Number): Kearny Pumps	PVK Location	Effective Duct Length (feet)	Inlet Aperture Location	Outside Wind: Direction	Outside Wind: Speed (fpm/mph)	Measured Volume of Air Delivered (cfm)	3-FOOT LEVEL Percent of Floor Area Having: ≥20 fpm	3-FOOT LEVEL: ≥40 fpm	6-FOOT LEVEL Percent of Floor Area Having: ≥20 fpm	6-FOOT LEVEL: ≥40 fpm
A	1A	10	0	North Side (Windows)	1,000	South Side	SW	75/.85	17,000	21	4	29	4
A	1B	10	4	North Side (Windows)	1,000	South Side	SW	75/.85	17,000	27	11	23	3
B	2A	10	0	NW Half (Windows)	1,000	W-4 Doors	W	195/2.2	15,000	48	15	26	12
B	2B	10	4	NW Half (Windows)	1,000	West End	SW	440/5.0	15,500	37	15	27	14
B	2C	10	4	NW Half (Windows)	1,000	West End	SW	85/.95	21,000	43	16	36	9
B	2D	10	0	NW Half (Windows)	1,000	W-2 Doors	N	325/3.7	18,000	32	9	18	5
C	10A	10	0	NE Corner (Windows)	1,000	West End	SW	120/1.4	30,000	93	66	86	54
C	10B	10	4	NE Corner (Windows)	1,000	West End	SW	315/3.6	34,500	100 1/	84 1/	98 1/	60 1/
D	11A	10	0	NE Corner (Windows)	1,000	SW Corner	SW	220/2.5	22,000	90	67	92	29
D	11B	10	2	NE Corner (Windows)	1,000	SW Corner	SW	220/2.5	22,000	100	95	100	57
E	12	10	0	NE Corner (Windows)	1,000	NW Corner	NE	265/3.0	27,500	96	43	81	23
F	13	10	3	NE Corner (Windows)	1,000	SE Half	E	180/2.0	22,000	69	20	80	25
G	14	10	3	NE Half (Windows)	1,000	SE Half	ENE	430/4.9	15,000	19	7	27	5
H	3A	10	0	East End (Doors)	8	West End	SW	210/2.4	37,000	83	30	94	59
H	3B	10	4	East End (Doors)	8	West End	SW	300/3.4	40,000	89	48	94	30
H	7	8	0	East End (Doors)	8	West End	WNW	240/2.7	40,000	93	69	88	57
H	9A	6	0	East End (Doors)	8	West End	SW	230/2.6	26,000	86	2/	86	2/
H	9B	4	0	East End (Doors)	8	West End	SW	355/4.0	23,500	25	2/	53	2/
H	9C	2	0	East End (Doors)	8	West End	SW	350/4.0	21,500	18	2/	29	2/
H	9D	3/	-	--	--	West End	SW	220/2.5	14,500	10	2/	12	2/
H	9E	4/	-	--	--	West End	SSW	275/3.1	10,500	75	2/	87	2/
I	4A1	10	0	East End (Doors)	14	SW Corner	NNE	275/3.1	28,000	96	66	90	40
I	4A2	10	0	East End (Doors)	8	SW Corner	NE	200/2.3	28,000	97	59	97	67
I	4B	10	4	East End (Doors)	14	SW Corner	NNE	275/3.1	28,000	97	84	98	68
J	5	10	0	East End (Doors)	8	NW & SW Corners	SW	65/.74	32,000	94	57	97	68
K	6	10	0	East End (Doors)	8	NW Corner	SW	175/2.0	26,500	76	53	84	64
L	8A	10	3	East End (Doors)	8	Mid. N & S Sides	W	30/.35	28,500	35	17	45	23
L	8B	10	4	East End (Doors)	8	Mid. N & S Sides	SW	220/2.5	29,500	45	22	53	25
L	8C	10	0	East End	8	Mid. N & S Sides	SSE	100/1.1	29,500	55	30	63	45

1/ Readings were taken only in the areas which previously had low airflow rates; these were eliminated by the Kearny pumps.

2/ The area having an airflow rate of 40 fpm or more in the tests with 6 or less fans was quite small and, consequently, the areas were not computed.

3/ In this test, the 10 PVKs were in place in the doors in the east end of the building but were not turned on.

4/ In this test, no equipment was present in the building and the doors in each end of the building were open.

Configuration B

The tests using this configuration had the 10 PVKs evenly spaced along the western half of the north wall of the test facility. The four doors in the west end were opened to permit air to enter. Using the PVKs alone, approximately 48 percent of the floor area at the 3-foot level and 26 percent of the floor area at the 6-foot level had measured airflow rates of 20 fpm or more. Two different arrangements of the four Kearny pumps were tested in an attempt to move air into the east end of the building. Neither of these arrangements was successful. The percentage at the 6-foot level was improved slightly but the percentage at the 3-foot level was decreased. A final attempt was made to increase air movement in the east end of the building by closing two of the air inlet doors to determine if the increased momentum of the entering air would carry it farther into the east end. This setup also failed to increase the floor area having 20 fpm airflow rates.

Configuration C

This configuration had the 10 PVKs located to exhaust air through the 10 easternmost windows along the north wall of the building. The fans were on the floor and exhausted air through 30-inch diameter polyethylene ducts which extended from the fans to the windows. The four doors in the west end of the building were opened to serve as air inlets.

The results for this test show that approximately 93 percent of the building had airflow rates of more than 20 fpm at the 3-foot level. A stagnant area was found along the south wall in the eastern half of the building and particularly the southeast corner of the building. It was anticipated that this corner would have low readings since the air was exhausted through the windows in the northeast corner of the building.

At the 6-foot level, approximately 86 percent of the building had readings of 20 fpm or more. The southeast corner was again the area having lowest readings.

Two Kearny pumps were then placed approximately 8 feet from the south wall at distances of 65 feet and 125 feet from the east wall in an effort to improve the airflow in the southeast corner. These pumps were arranged to pump air parallel to the south wall and toward the east end. This equipment placement eliminated the stagnant area in the southeast corner but created an area along the center of the building with readings of less than 20 fpm at the 3-foot level. The readings at the 6-foot level were greater than 20 fpm over the entire area. The initial conclusion drawn from this was that the Kearny pumps had diverted the flow of air away from the center area. To verify this conclusion, the Kearny pumps were removed and readings were taken again in the center area; again, low values were found to exist at the 3-foot level.

It was then suggested that perhaps the difference in outside temperature between the test without the Kearny pumps and the test with the Kearny pumps had changed the air density sufficiently to cause the readings near the floor to change. The test with the PVKs alone was begun at 6:30 a.m. when the outside temperature was approximately 70° F and the test using the Kearny pumps was begun at 11:30 a.m. when the outside temperature was approximately 82° F. The PVKs and Kearny pumps were left in position and the test with the Kearny pumps running was repeated the following morning at 7:00 a.m. The results of this test show that virtually all of the area had readings of 20 fpm or more at the 3-foot level. This was considered sufficient evidence to support the conclusion that the outside air density affects the airflow at the lower (3-foot) level.

Configuration D

The 10 PVKs were located the same as for Configuration C; in the northeast corner of the building. The 10 westernmost windows in the south wall were opened as air inlets.

The results for this configuration show that approximately 90 percent of the building had airflow rates of 20 fpm or more at the 3-foot level. The remaining 10 percent, which had readings of less than 20 fpm, was the southeast corner of the building and an area near the west end of the structure on the south side of the building. Approximately 67 percent of the building had measured airflow rates of more than 40 fpm at the 3-foot level.

The low readings in the southeast corner of the building were as expected and the low readings in the west end of the building were in the center of a large vortex created by the air entering the windows. The general direction of airflow after coming in through the windows was directly across the building to the opposite wall and then down the length of the building with a gradual widening of the airstream.

The results for the 6-foot level were quite similar to those for the 3-foot level.

Two Kearny pumps were placed in the west end of the building in the area where low readings were found. This resulted in readings of greater than 20 fpm for the area. No Kearny pumps were placed in the southeast corner since the configurations of the airflow contours were approximately the same as for the previous configuration, in which it was demonstrated that adding the Kearny pumps eliminated the stagnant area.

Configuration E

The 10 PVKs were in the same location for this configuration as they were for the two previous configurations. The 10 westernmost windows in the north wall were opened for air inlets. At the 3-foot level, airflow readings greater than 20 fpm were found for 96 percent of the floor area with 43 percent being more than 40 fpm.

Approximately 81 percent of the building had airflow readings greater than 20 fpm at the 6-foot level. The remaining 19 percent was along the eastern half of the south wall. This stagnant area was apparently caused by a combination of the structure along the south wall and the location of the exhaust fans. Approximately 23 percent of the building had airflow readings of more than 40 fpm at the 6-foot level. No Kearny pumps were added in the area of low readings along the south wall since the airflow contours were again similar to those of the previous configurations where it was shown that adding two Kearny pumps would eliminate the stagnant area.

Configuration F

The 10 PVKs were again left in the same location as for the three previous configurations, with 10 windows equally spaced along the eastern half of the south wall opened as air inlets. Three Kearny pumps were equally spaced across the middle of the building to pump air into the western half of the building.

Results for this configuration show that approximately 69 percent of the building had airflow readings of 20 fpm or more at the 3-foot level. At the 6-foot level about 45 percent of the building had airflow readings of 20 fpm or more. The difference between the 3- and 6-foot readings may be attributed to the fact that the test was started while raining with an outside temperature of 64° F and to the fact that the Kearny pumps tended to help more at the 3-foot level than at the 6-foot level.

Configuration G

This configuration had the 10 PVKs evenly spaced along the eastern half of the north wall. Kearny pump locations, air inlet apertures, and ducting were identical with the previous configuration.

The results for this test show that approximately 27 percent of the building had airflow rates of 20 fpm or more at the 6-foot level and that 19 percent of the building had readings of 20 fpm or more at the 3-foot level.

The total volume of air delivered was 14,800 cfm. Comparing this with the 21,680 cfm delivered in Configuration H implies that there may be advantages in concentrating the PVKs in one area rather than distributing them over a larger area. There is not sufficient evidence to justify a conclusion to this effect; however, it is felt that further investigation is warranted.

<u>Configuration H</u>

Air was exhausted through the two large doors in the east end of the building and the four single doors in the west end served as air inlets. Several tests were performed using this configuration.

The first test had five PVKs exhausting air through each of the two large doors in the east end of the building. The results for this arrangement show that adequate airflow rates (20 fpm or more) existed for approximately 94 percent of the building at the 6-foot level, which was better than the 3-foot level where approximately 83 percent of the floor area had adequate airflow.

Kearny pumps were positioned perpendicular to the main airstream to pump air into the stagnant area along the south wall. This resulted in improved air movement in the south area but created another stagnant area along the north wall. Readings in these areas were repeated with the Kearny pumps both on and off and the stagnant area along the north wall was concluded to be a direct result of the Kearny pumps. With the Kearny pumps running, the percent of the floor area having airflow readings of 40 fpm or more at the 6-foot level actually decreased from 59 percent to 30 percent. On the basis of this test and the results of other tests with the Kearny pumps oriented parallel to the main airstream, it is concluded that the preferred orientation of the Kearny pumps is parallel to the direction of airflow.

The permanent structure on the south side of the building obviously affected the shape of the airflow contours for the initial test; however, another influence on the readings at both the 3-foot and 6-foot levels was suspected to be the fan arrangement in the two doors. For the northernmost door, the fans were located so that three fans had very short ducts and, consequently, very little backpressure due to ducting. The fans on the southernmost door were arranged, however, so that each fan had at least a 4-foot 8-inch duct with the average effective duct being about 8 feet long, which could explain in part the higher readings along the north side of the building.

In order to determine the magnitude of the effect the different fan arrangements had on the airflow, the fans in the southernmost door were rearranged to agree with those in the northernmost door. The results for this revised fan arrangement show that much of the airflow contour shape in the initial test was due to the less efficient fan arrangement, and that more than 80 percent of the building had measured airflow rates of greater than 40 fpm with the remaining 20 percent of unobstructed area having greater than 20 fpm.

The structure on the south side of the building obviously caused the lower readings for the southeast part of the building. Without this protrusion, this fan and air inlet configuration should result in adequate airflow rates for the entire floor area.

Additional tests performed using this basic configuration consisted of tests using 8, 6, 4, 2, and none of the fans. The purpose of this was to establish the point at which a significant portion of the floor area has less than adequate air movement. In those areas of the country having a zonal requirement of less than 15 cfm per occupant, fewer than 10 fans would be allocated to a shelter of this size and having this type of aperture configuration. This series of tests was an effort to evaluate the air movement which might be expected in these lower cfm areas. The results of these tests show that six fans, which would be applicable to a 10 cfm per occupant requirement, provide adequate air movement over a large portion (86 percent at both levels) of the floor area but that four fans provide adequate air movement for only 25 percent of the floor area at the 3-foot level and 53 percent at the 6-foot level.

In a geographic area with a 5 cfm per occupant requirement, only three fans would be allocated to a shelter this size. Based on these tests, adequate air movement would not be obtained with three fans.

The test with no fans running was first performed with the fans in place in the two large doorways. This resulted in only a very small portion of the floor area (6 percent at the 6-foot level, 19 percent at the 3-foot level) having measured airflow rates of 20 fpm or more. The fans were removed and the test was repeated; approximately 75 percent of the floor area had adequate air movement (20 fpm) at the 3-foot level and 88 percent at the 6-foot level. This indicates that the natural ventilation for this configuration provides adequate air movement for most of the shelter area. It should be noted, however, that this is not a typical configuration for shelters in the NFSS which require additional ventilation from a natural ventilation standpoint, since it is totally above ground.

On the day this test was performed the outside wind was out of the south-southwest at an average speed of 275 fpm with gusts of 500 fpm.

The total volume of air entering the building with 0, 2, 4, 6, 8, and 10 fans running was computed using the measured speed of the air entering the building through the inlet apertures. These data were used to construct a curve for the number of fans versus volume of air delivered which is shown in Figure 12. Since this curve is virtually linear, it indicates that no significant pressure head is built up due to inlet aperture constriction with up to 10 fans in operation.

Configuration I

In this test, the PVKs were located as in the previous configuration in the east end of the building. The 10 westernmost windows in the south wall were opened to serve as air inlets.

Results for this test show that adequate air movement existed throughout the building except for two small areas; one along the eastern half of the south wall and the other near the center of the west half of the south wall. Adding the Kearny pumps in these areas eliminated the readings of less than 20 fpm and significantly increased the area having 40 fpm or more. For this test, the Kearny pumps were positioned to pump air parallel to the general direction of airflow.

This test was repeated with the fans rearranged as discussed for the previous configuration, with the result that airflow rate readings of 20 fpm or more existed throughout the building without the Kearny pumps.

Configuration J

In this test, the PVKs remained as before in the more efficient arrangement described for Configuration H. The five westernmost windows in both the north and south walls were opened as air inlets.

The results show that air movement of at least 20 fpm existed throughout the building except for a small stagnant area along the south wall. At the 6-foot level, approximately 65 percent of the building had readings of more than 40 fpm with many of these readings, particularly along the north wall, being from 50 to 100 fpm.

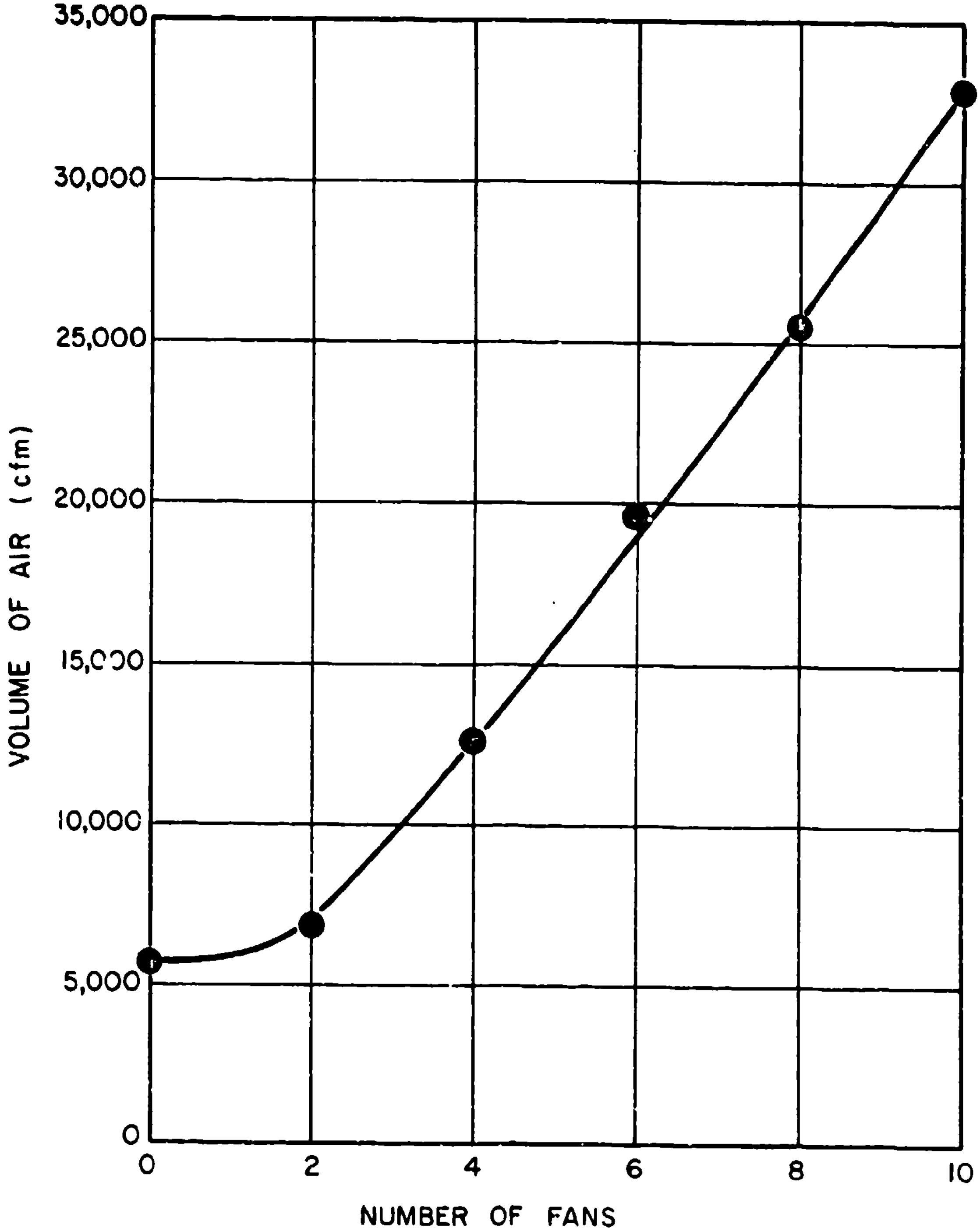


Fig. 12. Air Volume Versus Number of Fans.

Kearny pumps were not used in this configuration since it had previously been demonstrated that they are capable of eliminating stagnant areas such as existed in this test.

Configuration K

In this test, the PVKs were again in the east end of the building. The 10 westernmost windows in the north wall were opened and served as air inlets.

The results for this configuration show that adequate air movement existed throughout most of the building; the only exceptions again being along the east end of the south wall and a small area about 100 feet from the west end of the building and 20 to 40 feet from the north wall at the 6-foot level. This latter stagnant area was apparently the center of a large eddy set up by the air entering the apertures. Further evidence of this is that movement of air between the stagnant area and the north wall was back toward the inlet apertures.

The general pattern of air movement was from the apertures to the opposite wall and then down the south wall initially and spreading over a larger area as the PVKs were approached. This pattern implies that the momentum of the air as it enters the building is sufficient to carry it across the building to the opposite wall. Kearny pumps were not used in this configuration since previous tests had demonstrated their effectiveness in this type of application.

Configuration L

In this configuration, the 10 exhaust fans were located in the east end of the building as for several previous configurations. Five windows on each side of the building approximately 115 to 130 feet from the east end of the building were opened as air inlets.

In the first test, three Kearny pumps were located approximately 130 feet from the east end of the building and equally spaced between the north and south walls. The Kearny pumps were oriented to pump air toward the west end of the building. The results for this arrangement show that the area with adequate air movement extended approximately 175 feet from the east end except for several small isolated spots at each measurement level in which the airflow readings were less than 20 fpm. These were apparently caused by localized eddy currents and fluctuations due to wind gusts.

In the second test, four Kearny pumps were equally spaced between the north and south walls at a distance of approximately 155 feet from the east end. These pumps forced air toward the west end of the building. This arrangement extended the amount of floor area having adequate air movement to 210 feet from the east end of the building although there were again several isolated spots having readings less than 20 fpm.

A third test was run with the exhaust fans and air inlets located the same as for the first two tests; however, no Kearny pumps were used. The results for this test show that adequate air movement existed for the area extending 155 feet from the east end of the building. In addition, an area along the north wall extending to about 270 feet from the east end had airflow readings of more than 20 fpm. One difference between these results and those of the two previous tests with the Kearny pumps was that fewer isolated spots of stagnant air were found. One possible explanation for this is that the Kearny pumps created isolated eddy currents.

IV. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the results of the tests described herein, the following conclusions and recommendations are made.

a) Effective duct length is the single most decisive element in system performance and should be kept to a minimum. Although this has been demonstrated in previous research, its significance warrants reiteration here.

b) On the basis of evidence observed during these tests, it is recommended that the effect of clustering the PVKs versus having them separated from one another be investigated in subsequent research.

c) The cross-sectional area of the airflow path through a shelter should be kept to a minimum. Stated another way, the length of the airflow path should be maximized. The reason for this is obvious since the wind speed, S, is inversely proportional to the cross-sectional area, A, of the flow path for a given quantity of air, Q, as shown in the equation $S = Q/A$.

   This assumes that the airflow rate is the same over the entire cross-sectional area, which is not completely true but the tendency is in this direction. To illustrate this, Configuration D or E would be more effective (i.e., would produce higher airflow rates) than Configuration A.

d) The largest shelter which can be adequately ventilated in the 15, 10, and 7.5 cfm per occupant zones, using the recommended number of PVKs, is larger than the facility used in these tests, provided widely separated apertures are available for air supply and exhaust. However, a shelter this size is not adequately ventilated in the 5 cfm per occupant zone using the recommended number of PVKs.

e) The combination of air leaking into the building through sources other than the inlet apertures and variations in outside wind conditions caused large deviations in the measured volume of air delivered to the test facility by the ten PVKs relative to the value predicted by the performance curves.

f) In large shelters, the orientation of air inlet apertures has little or no effect on system performance so long as they are remote from the exhaust apertures. This is illustrated by the results of Configurations C, D, and E, all of which had the PVKs exhausting through the windows in the northeast corner of the building with the location of air inlet apertures changed; or by the results of Configurations H, I, J, and K, all of which had the PVKs exhausting through the doors in the east end of the building with the location of the air inlet apertures changed.

g) During the tests, it was concluded that the density of the ventilating air had a direct effect on the airflow rate near the floor. Although this is not a controllable factor, the measured wind speeds at the 3-foot level were significantly higher for lower temperature air (higher density) passing through the shelter than for higher temperature air (lower density).

h) The use of Kearny pumps to move air large distances (greater than 50 to 60 feet) outside the airflow path through a shelter is not practical. This was demonstrated in Configurations B, F, G, and L. Effective ventilation of these areas would require placing PVKs in the areas and exhausting through long ducts. This, of course, would increase the ventilation costs of these shelters.

i) The effectiveness of Kearny pumps used to distribute air in otherwise stagnant areas is highly dependent on the orientation of the Kearny pumps relative to the main airstream direction of flow. These tests indicate that much greater effectiveness is obtained when Kearny pumps are deployed such that air is pumped in the same general direction as the airstream.

j) As expected, Kearny pumps are more effective in increasing the airflow rate at the 3-foot level than at the 6-foot level.

k) The percent of floor area having an airflow rate of 20 fpm, or more, was 100 percent in the optimum configuration and ranged from 19 percent to 98 percent for the other configurations using 10 fans. In those cases which had less than 100 percent of the floor area adequately ventilated, additional ventilation equipment can be added to increase the usable shelter area; otherwise, the capacity of the shelter must be decreased.

l) In order to utilize information from this study to estimate future purchasing requirements and subsequently to allocate ventilation equipment to shelters, the location of exterior apertures in a shelter should be known. Additional study is required to determine if data already contained in the NFSS are adequate for this purpose.

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5. Personal Communication with Donald A. Bettge, Office of Civil Defense, Washington, D. C., March 1971.

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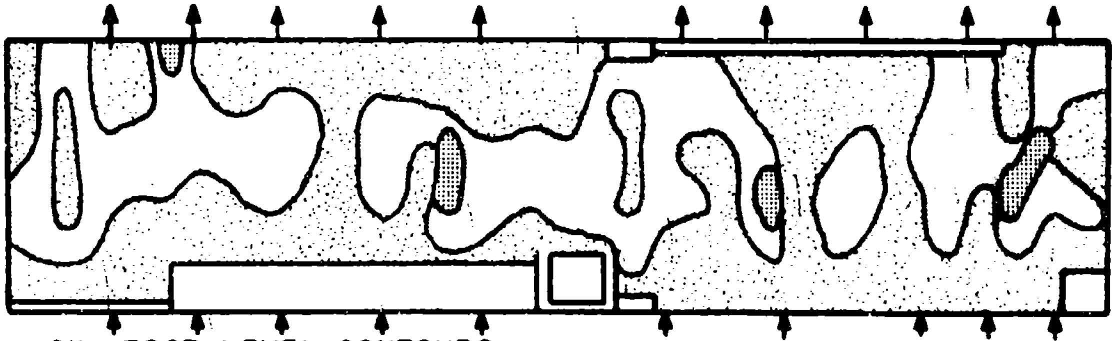
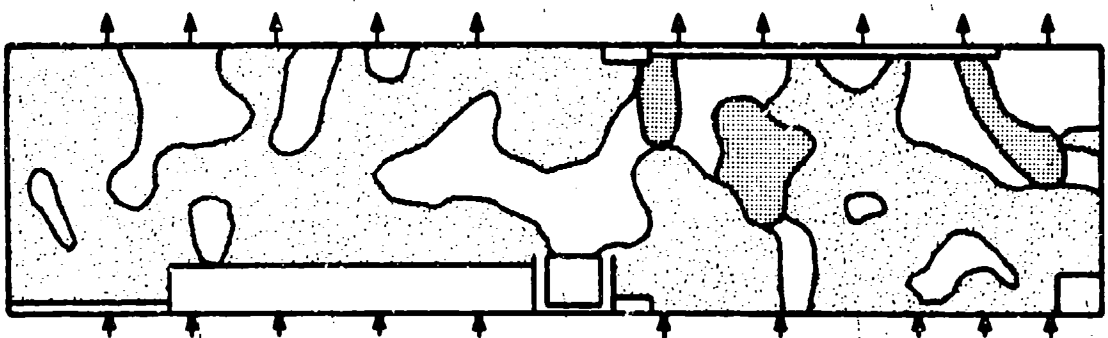
Appendix A

Airflow Rate Contours

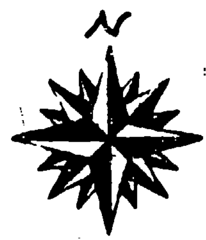


a. SIX - FOOT LEVEL CONTOURS.



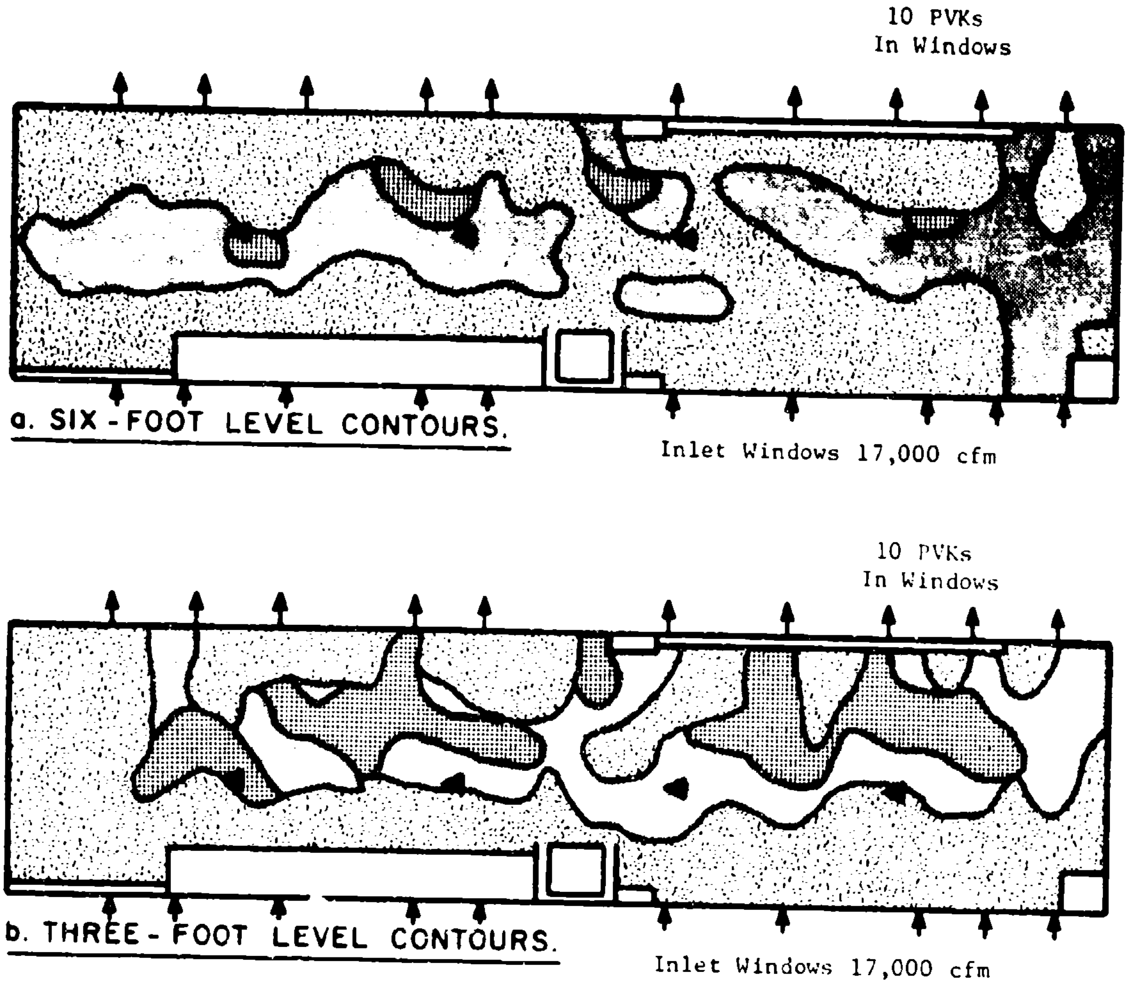
b. THREE - FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	79	71
20-40 fpm	17	25
> 40 fpm	4	4

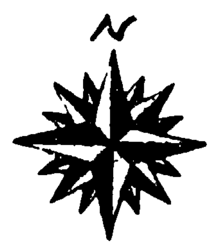


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ .85 mph

Fig. A-1. Airflow Rate Contours for Test Number 1A, Configuration A.

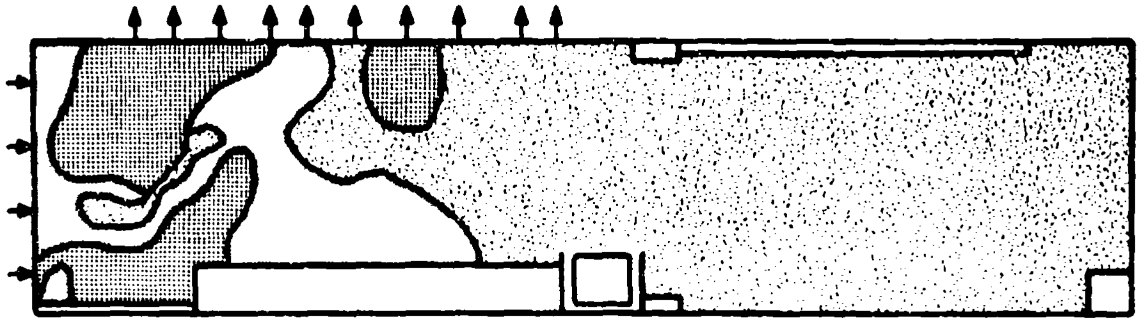


AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	73	77
20-40 fpm	16	20
>40 fpm	11	3

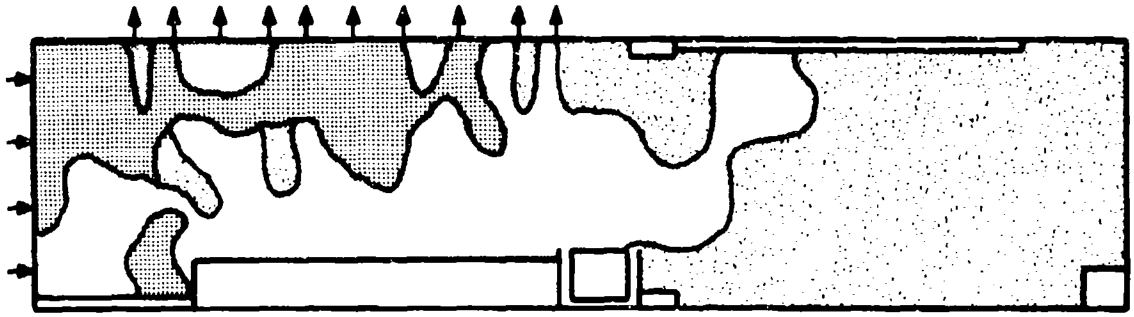


Kearny Pumps (▶) Used: 4
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ .85 mph

Fig. A-2. Airflow Rate Contours for Test Number 1B, Configuration A.

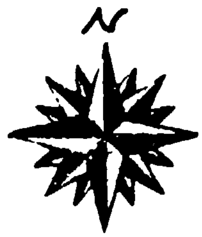


a. SIX-FOOT LEVEL CONTOURS.



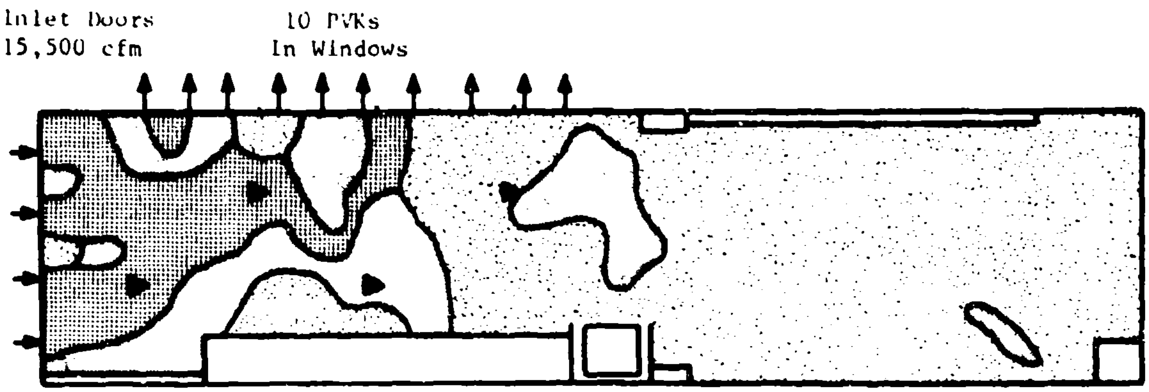
b. THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	52	74
20-40 fpm	33	14
> 40 fpm	15	12

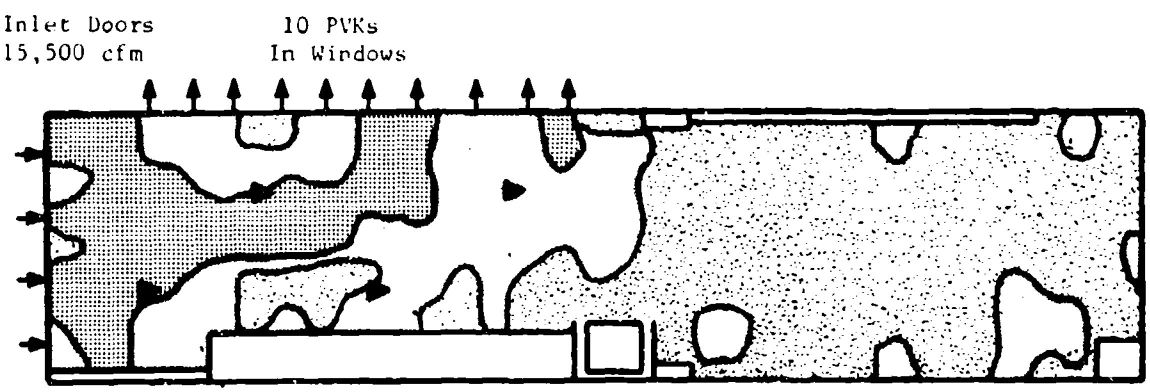


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 1,000 feet
Outside Wind: W @ 2.2 mph

Fig. A-3. Airflow Rate Contours for Test Number 2A, Configuration B.



a. SIX-FOOT LEVEL CONTOURS.

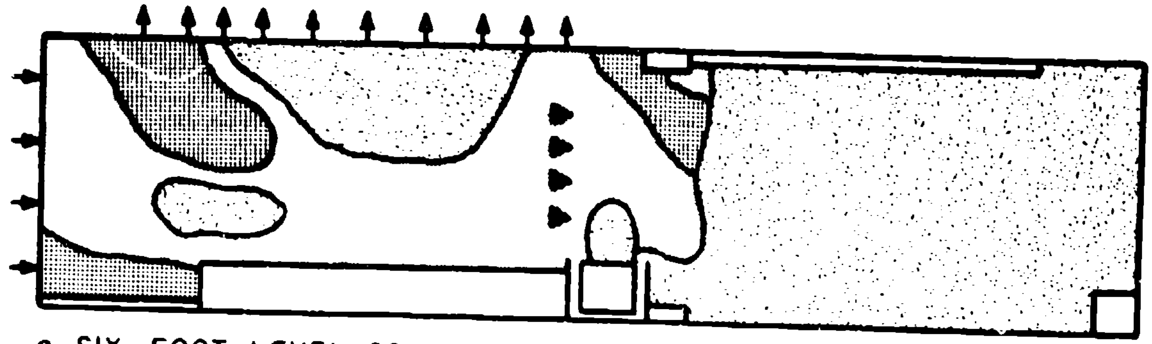


b. THREE-FOOT LEVEL CONTOURS.

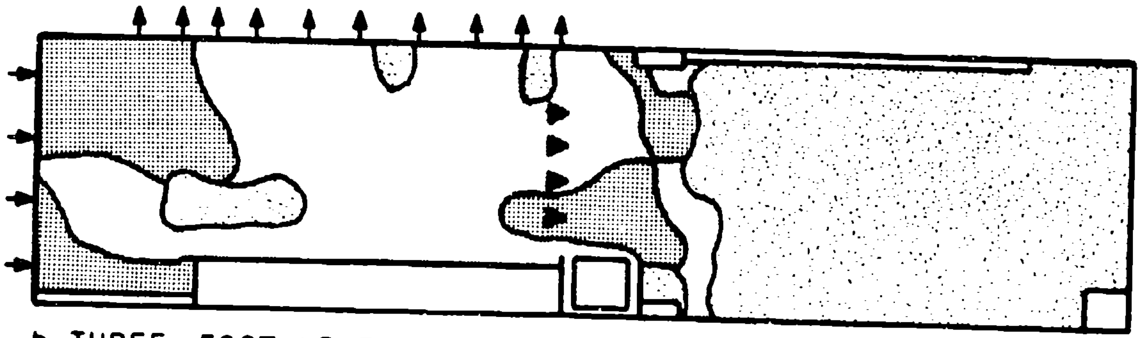
	PERCENT OF AREA COVERED	
AIRFLOW RATES	3-Foot Level	6-Foot Level
< 20 fpm	63	73
20-40 fpm	22	13
> 40 fpm	15	14

Kearny Pumps (▶) Used: 4
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ 5.0 mph

Fig. A-4. Airflow Rate Contours for Test Number 2B, Configuration B.



a. SIX - FOOT LEVEL CONTOURS.

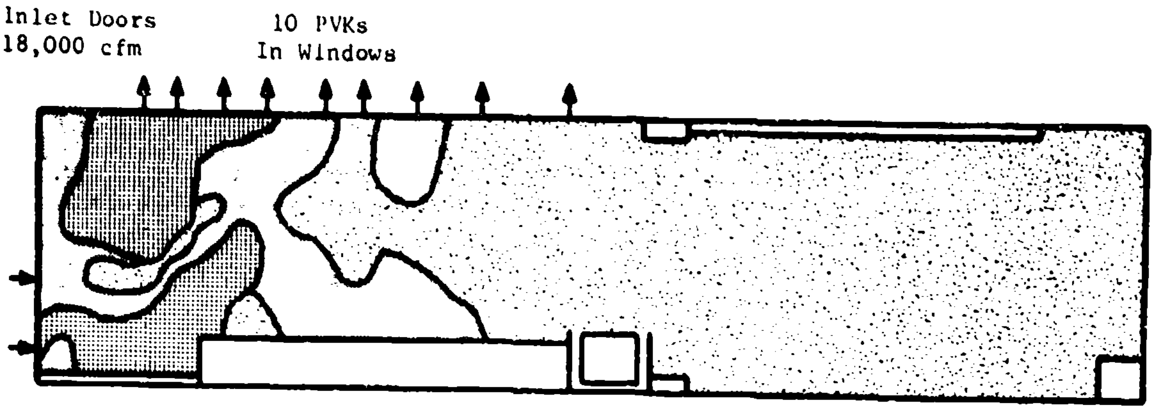


b. THREE - FOOT LEVEL CONTOURS.

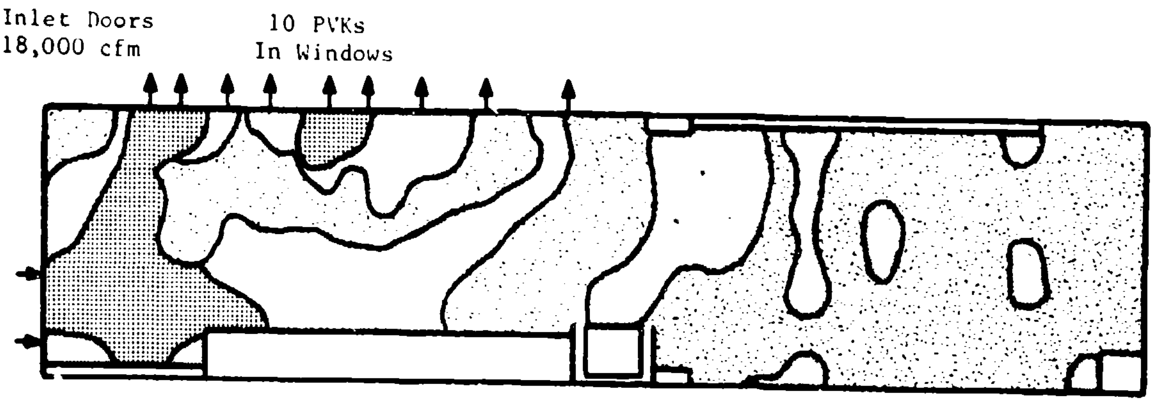
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	57	64
20 - 40 fpm	27	27
> 40 fpm	16	9

Kearny Pumps (▶) Used: 4
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ .95 mph

Fig. A-5. Airflow Rate Contours for Test Number 2C, Configuration B.

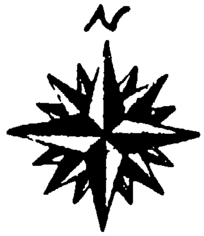


a. SIX - FOOT LEVEL CONTOURS.



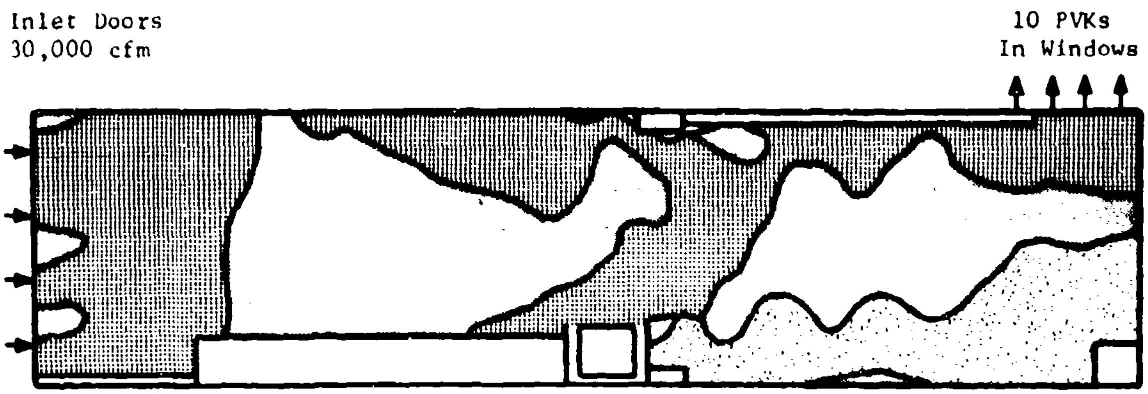
b. THREE - FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	68	82
20 - 40 fpm	23	13
>40 fpm	9	5

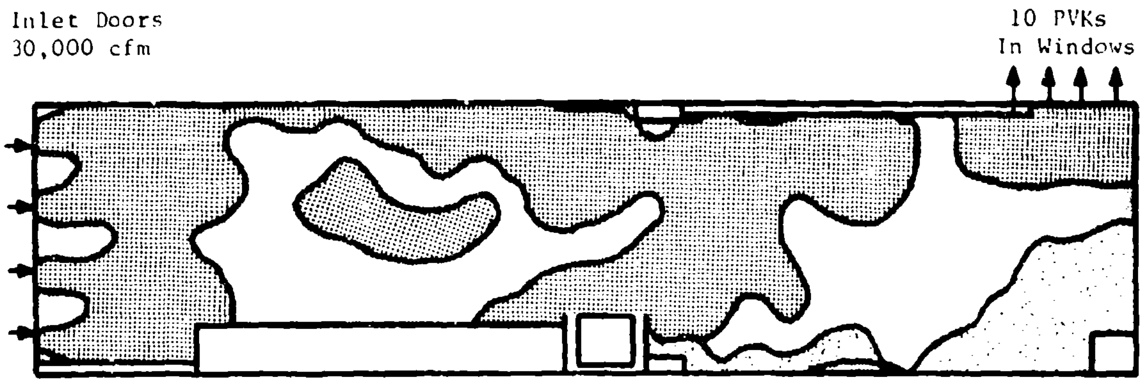


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 1,000 feet
Outside Wind: N @ 3.7 mph

Fig. A-6. Airflow Rate Contours for Test Number 2D, Configuration B.

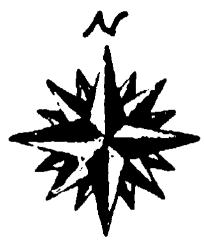


a. SIX - FOOT LEVEL CONTOURS.



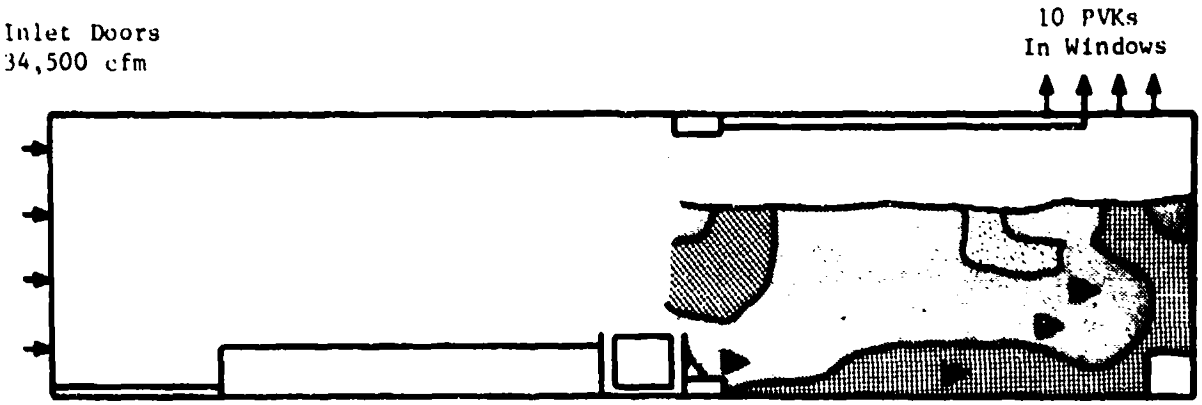
b. THREE - FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	7	14
20 - 40 fpm	27	32
> 40 fpm	66	54

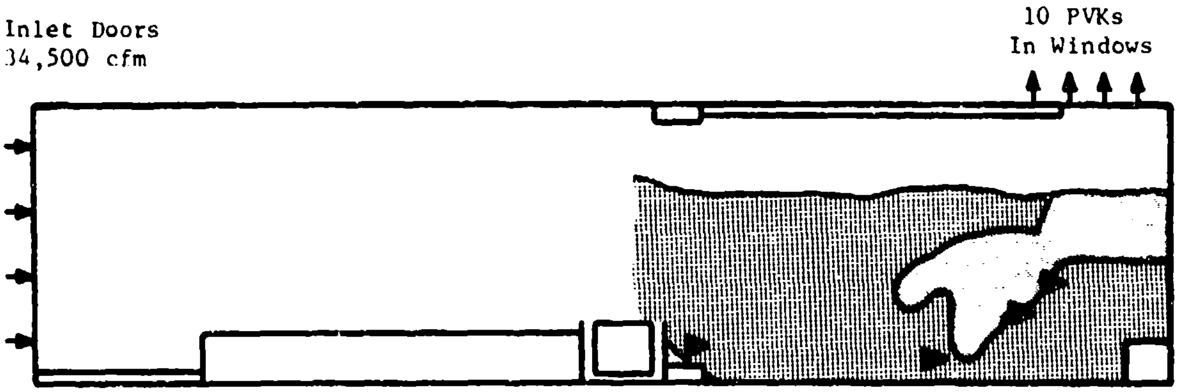


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ 1.4 mph

Fig. A-7. Airflow Rate Contours for Test Number 10A, Configuration C.

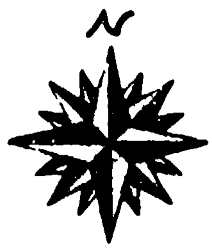


a. SIX-FOOT LEVEL CONTOURS.



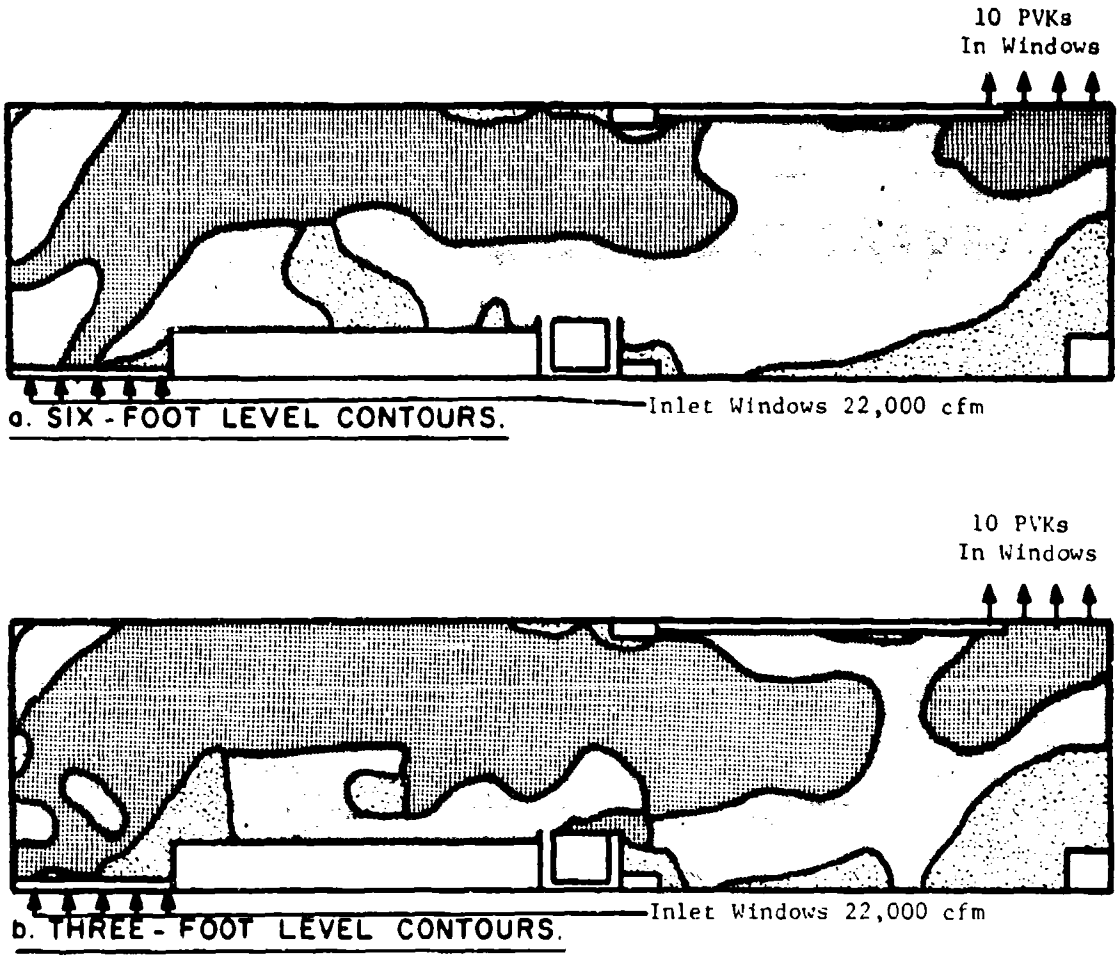
b. THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	0	2
20-40 fpm	16	38
> 40 fpm	84	60

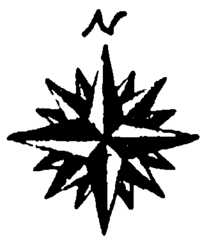


Kearny Pumps (▶) Used: 4
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ 3.6 mph

Fig. A-8. Airflow Rate Contours for Test Number 10B, Configuration C.

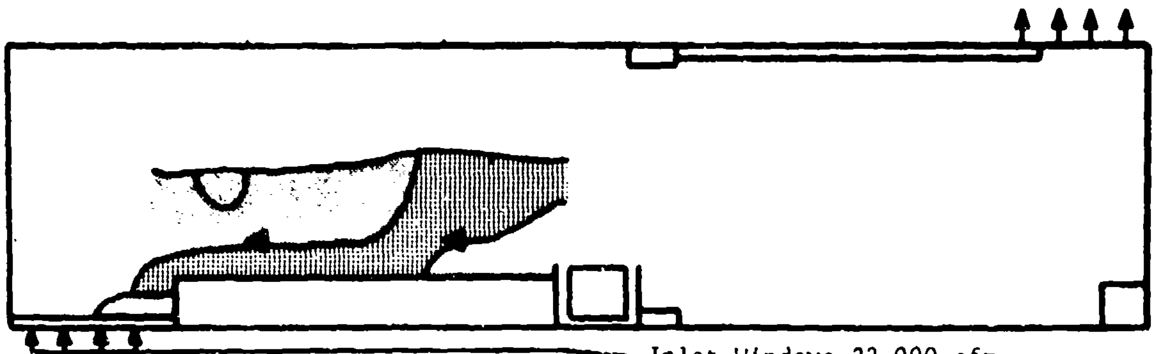


AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	PERCENT OF AREA COVERED 6-Foot Level
< 20 fpm	10	8
20-40 fpm	23	63
> 40 fpm	67	29

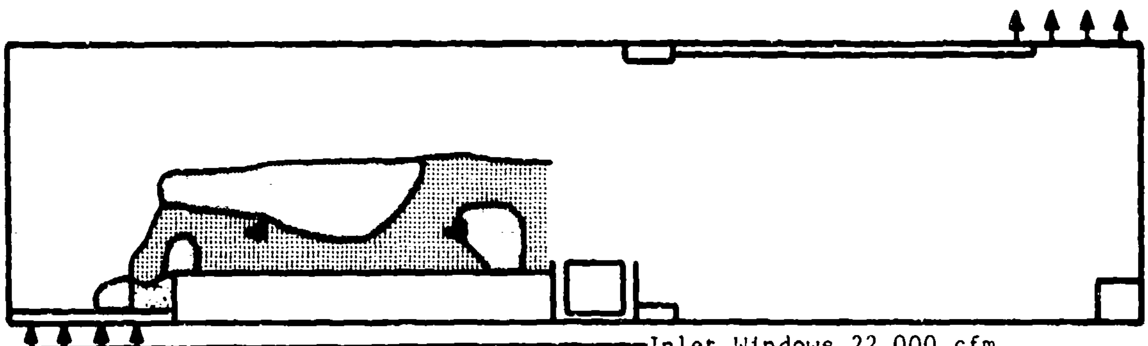


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ 2.5 mph

Fig. A-9. Airflow Rate Contours for Test Number 11A, Configuration D.

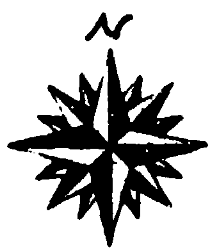


a. SIX-FOOT LEVEL CONTOURS.



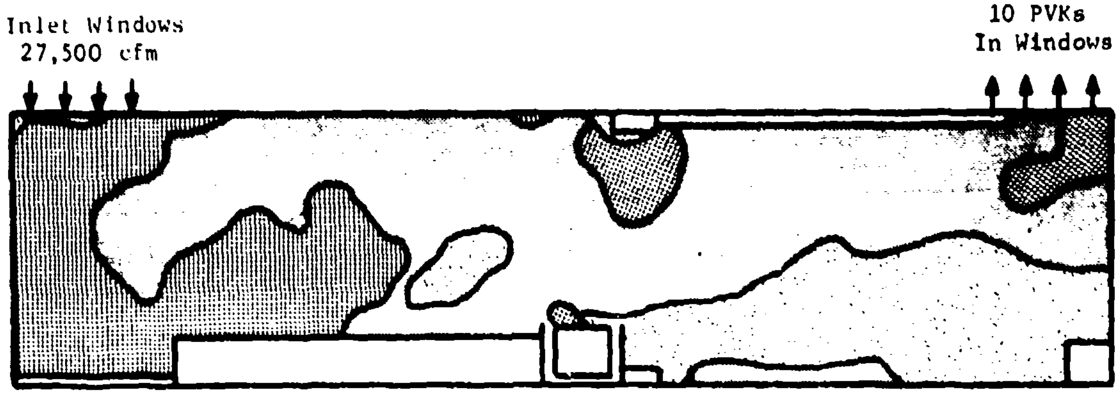
b. THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	0	0
20-40 fpm	5	43
>40 fpm	95	57

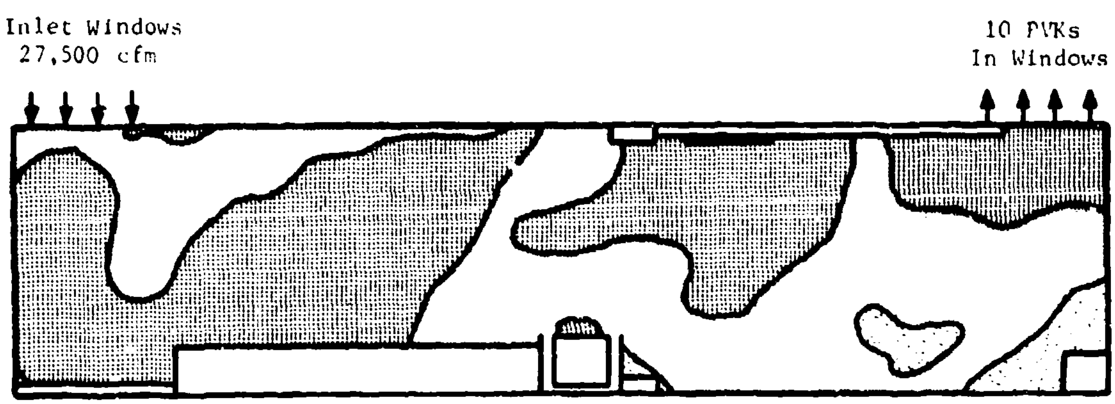


Kearny Pumps (▶) Used: 2
PVK Effective Duct Length: 1,000 feet
Outside Wind: SW @ 2.5 mph

Fig. A-10. Airflow Rate Contours for Test Number 11B, Configuration D.



a. SIX - FOOT LEVEL CONTOURS.

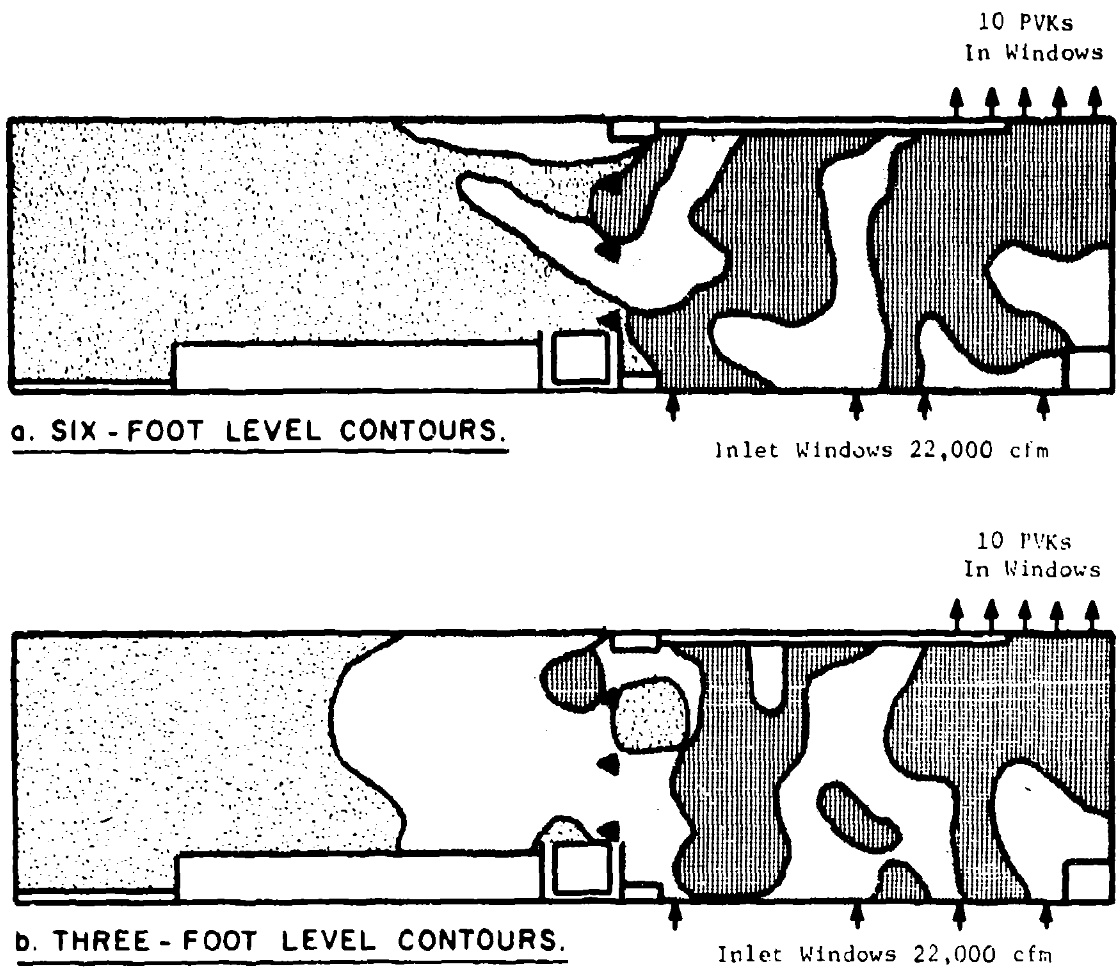


b. THREE - FOOT LEVEL CONTOURS.

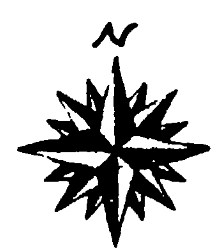
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	4	19
20 - 40 fpm	53	58
> 40 fpm	43	23

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 1,000 feet
Outside Wind: NE @ 3.0 mph

Fig. A-11. Airflow Rate Contours for Test Number 12, Configuration E.

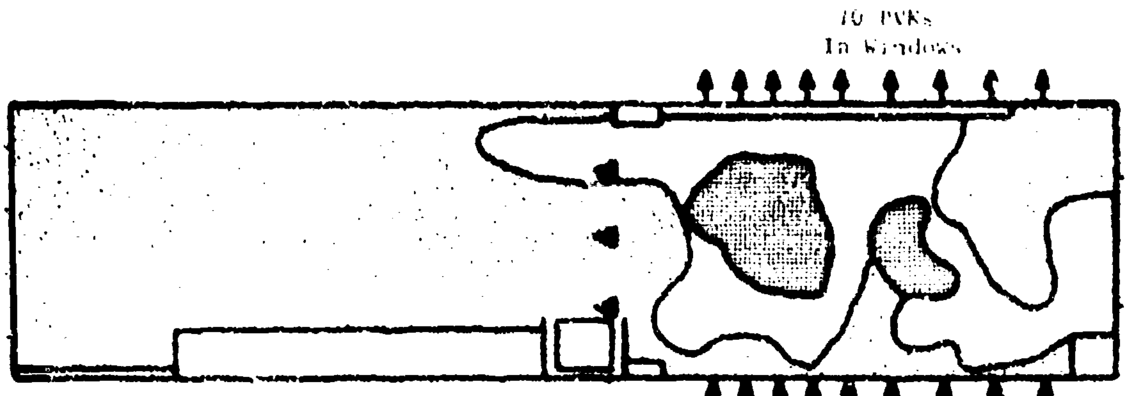


AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	PERCENT OF AREA COVERED 6-Foot Level
< 20 fpm	31	20
20 - 40 fpm	49	55
> 40 fpm	20	25



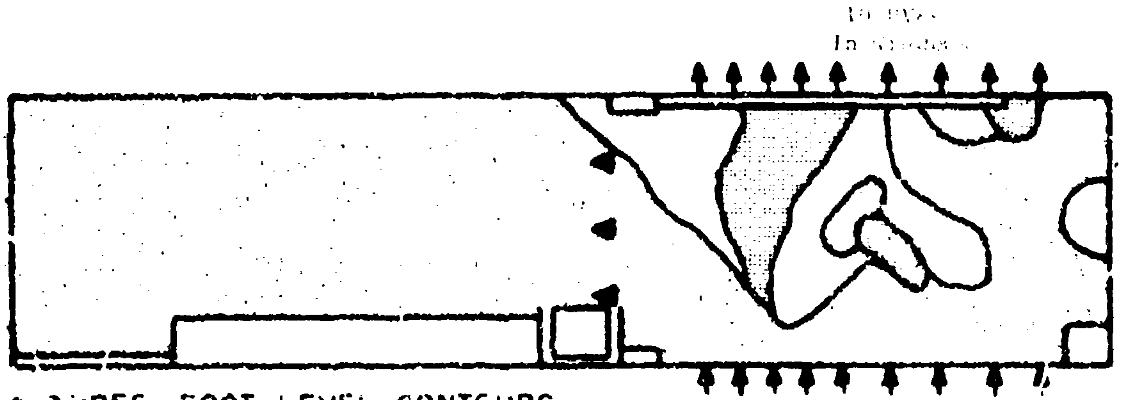
Kearny Pumps (▶) Used: 3
PVK Effective Duct Length: 1,000 feet
Outside Wind: E @ 2.0 mph

Fig. A-12. Airflow Rate Contours for Test Number 13, Configuration F.



a. SIX - FOOT LEVEL CONTOURS.

Inlet Windows 35,000 cfm



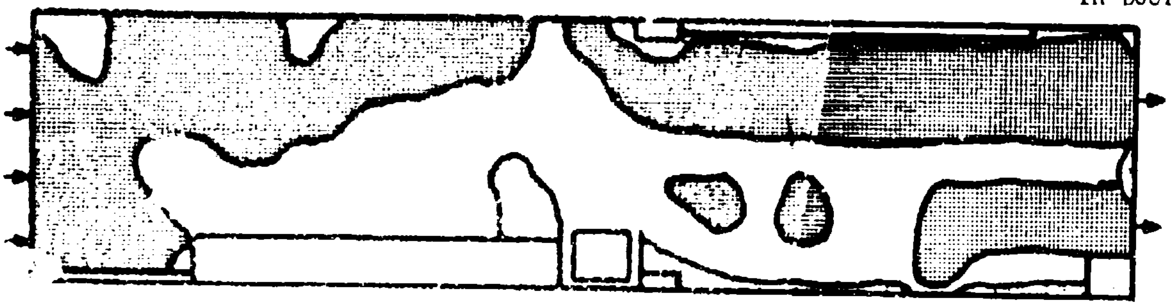
b THREE - FOOT LEVEL CONTOURS.

Inlet Windows 35,000 cfm

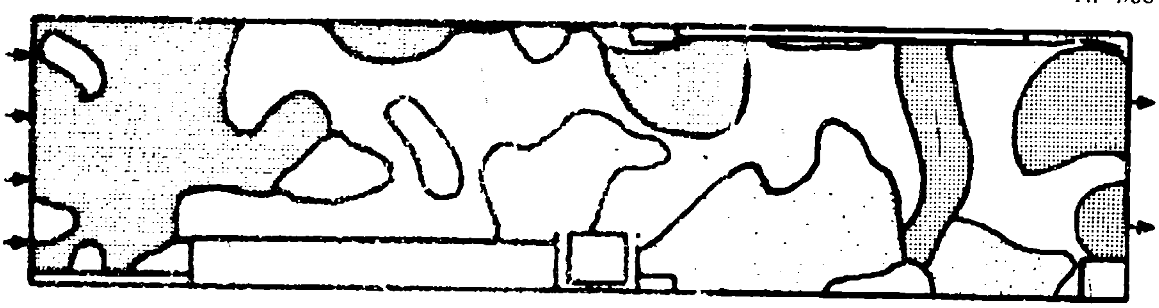
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	81	73
20 - 40 fpm	12	22
> 40 fpm	7	5

[illegible] (▶) Used: 3
PVK Effective Duct Length: 3,000 feet
Outside Wind: [illegible] 4.4 mph

Fig. A-12. Airflow Rate contours for Test Number [illegible], Configuration [illegible].



a. SIX-FOOT LEVEL CONTOURS



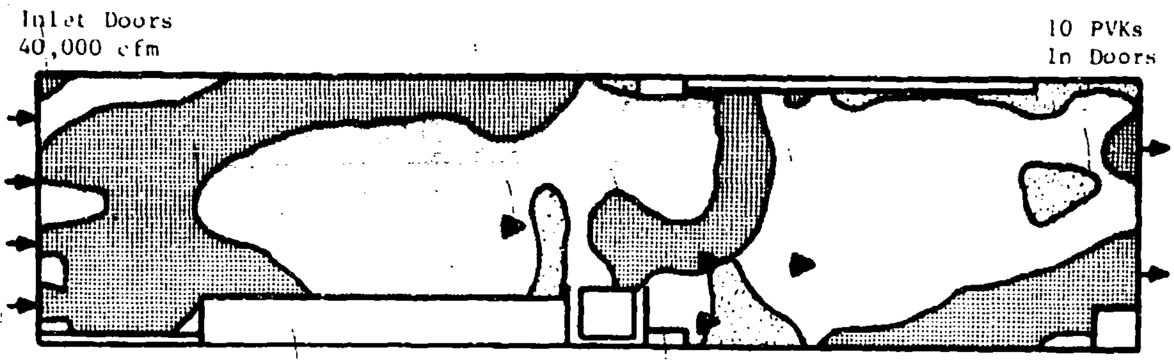
b THREE-FOOT LEVEL CONTOURS

AIRFLOW RATES

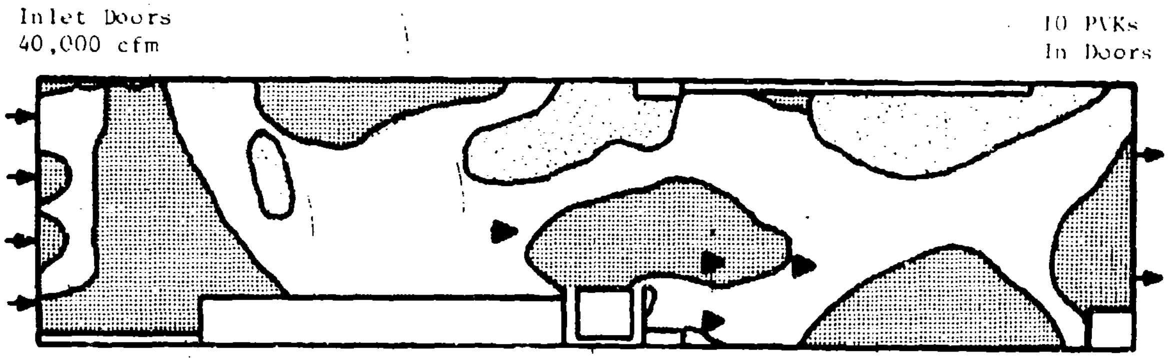
	[illegible]	
	[illegible]	[illegible] Level
< 20 fpm	[illegible]	[illegible]
20-40 fpm	[illegible]	[illegible]
> 40 fpm	[illegible]	59

[illegible]

Fig. A-[illegible]. Airflow Rate Contours for Test Number 3A, Configuration [illegible]



a. SIX - FOOT LEVEL CONTOURS.

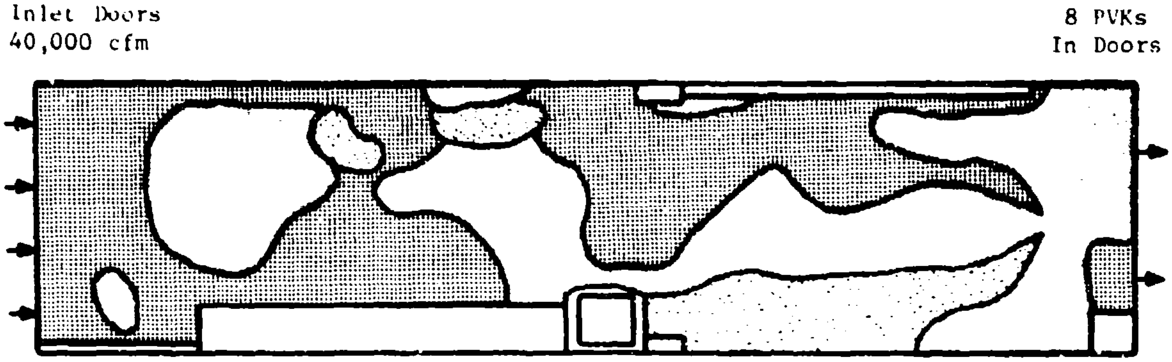


b. THREE - FOOT LEVEL CONTOURS.

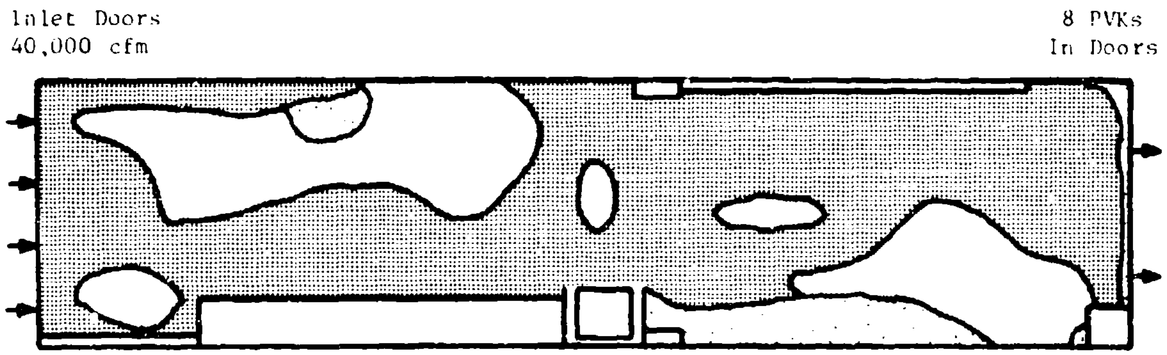
AIRFLOW RATES	PERCENT OF AREA COVERED: 3-Foot Level	6-Foot Level
< 20 fpm	11	6
20 - 40 fpm	41	64
> 40 fpm	48	30

Kearny Pumps (▶) Used: 4
PVK Effective Duct Length: 8 feet
Outside Wind: SW @ 3.4 mph

Fig. A-15. Airflow Rate Contours for Test Number 3B, Configuration H.



a. SIX-FOOT LEVEL CONTOURS.

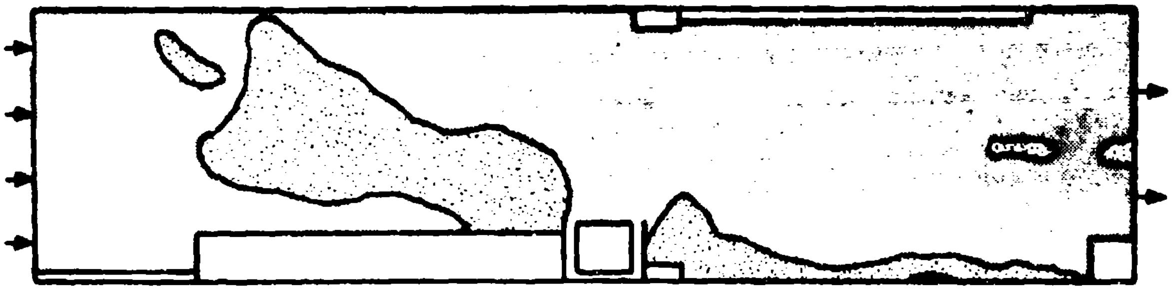


b. THREE-FOOT LEVEL CONTOURS.

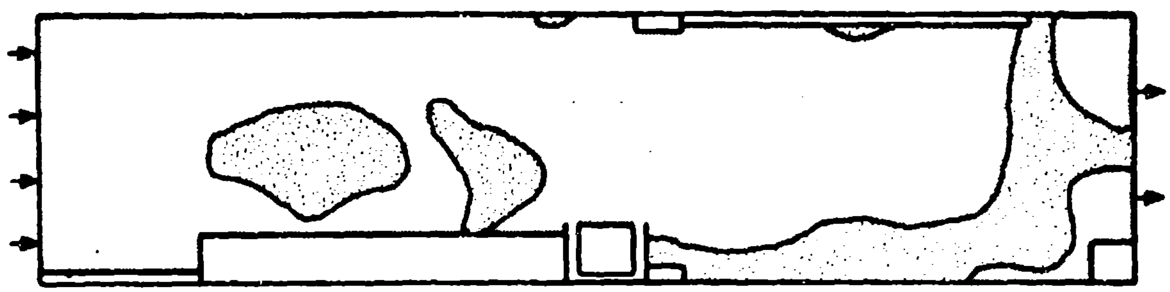
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	7	12
20-40 fpm	24	31
> 40 fpm	69	57

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: WNW @ 2.7 mph

Fig. A-16. Airflow Rate Contours for Test Number 7, Configuration H.

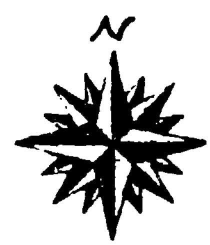


a. SIX-FOOT LEVEL CONTOURS.



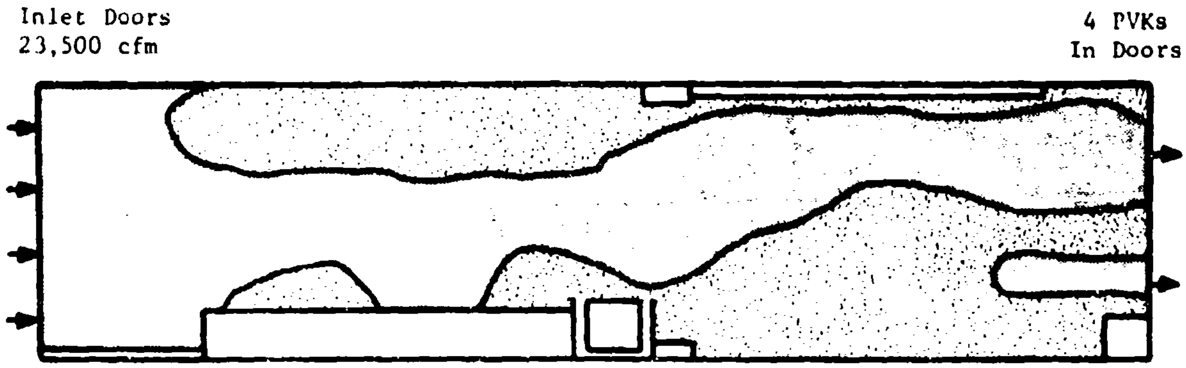
b. THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED: 3-Foot Level	PERCENT OF AREA COVERED: 6-Foot Level
< 20 fpm	14	14
20 - 40 fpm > 40 fpm	86	86

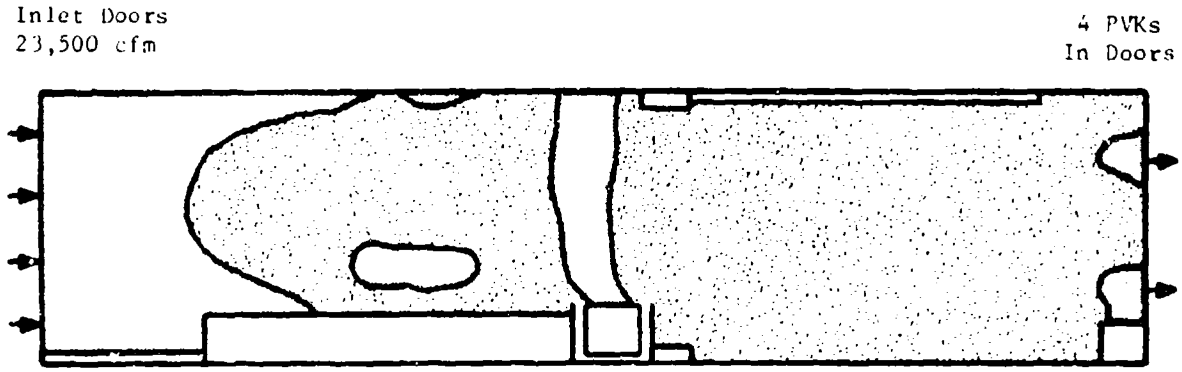


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: SW @ 2.6 mph

Fig. A-17. Airflow Rate Contours for Test Number 9A, Configuration H.



a. SIX-FOOT LEVEL CONTOURS.

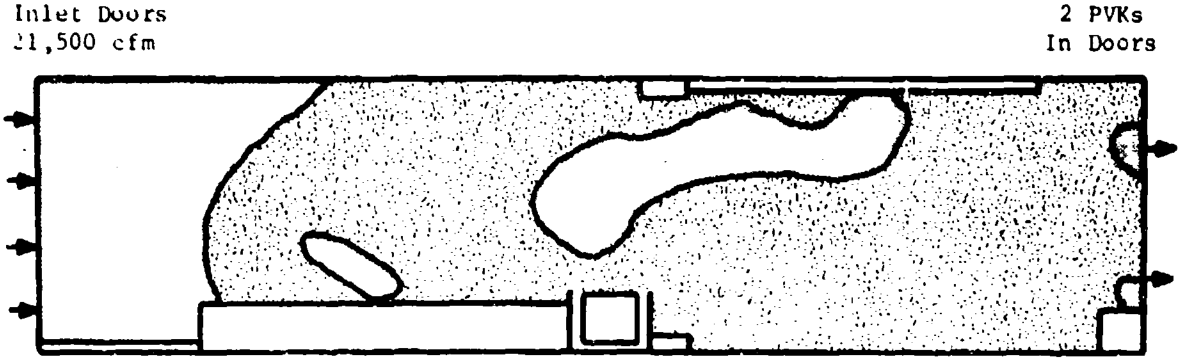


b. THREE-FOOT LEVEL CONTOURS.

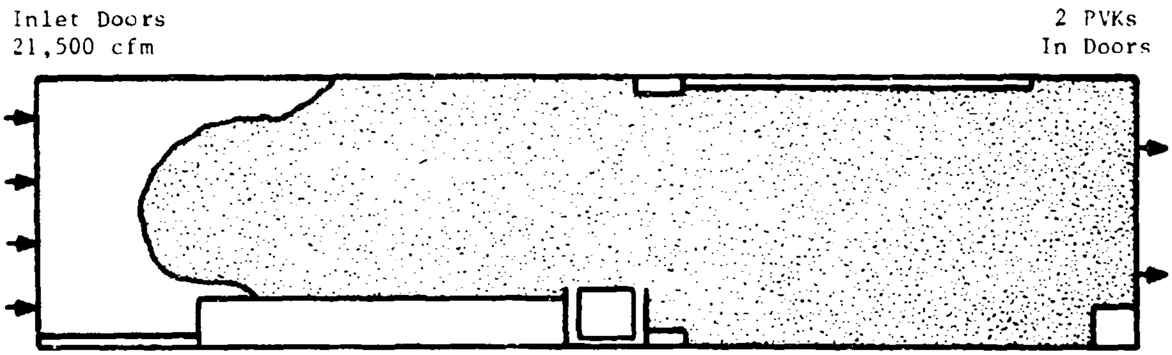
	PERCENT OF AREA COVERED	
AIRFLOW RATES	3-Foot Level	6-Foot Level
< 20 fpm	75	47
20-40 fpm > 40 fpm	25	53

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: SW @ 4.0 mph

Fig. A-18. Airflow Rate Contours for Test Number 9B, Configuration H.



a. SIX - FOOT LEVEL CONTOURS.

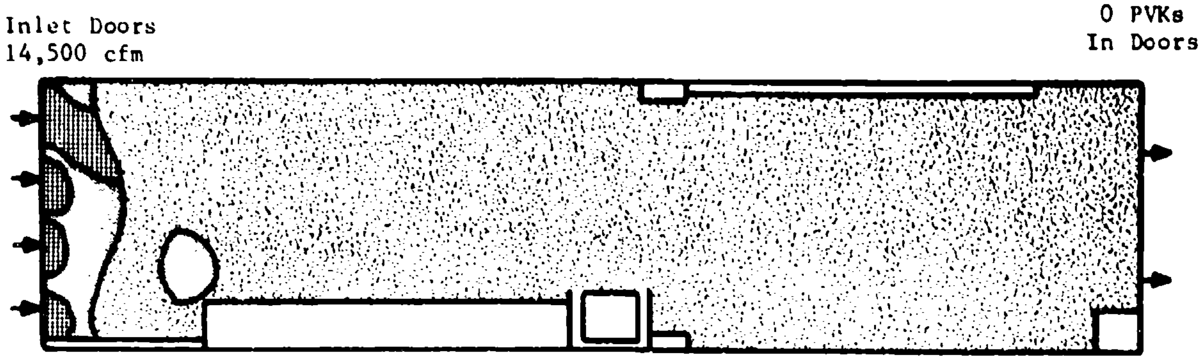


b. THREE - FOOT LEVEL CONTOURS.

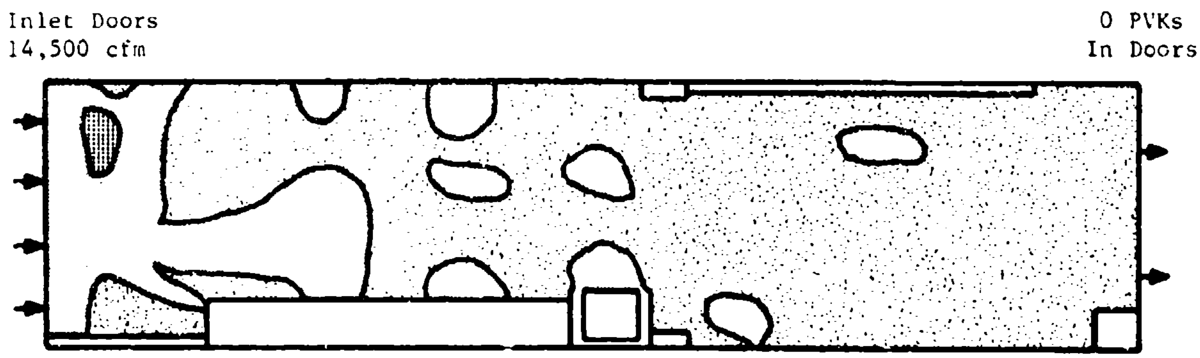
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	82	71
20 - 40 fpm; > 40 fpm	18	29

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: SW @ 4.0 mph

Fig. A-19. Airflow Rate Contours for Test Number 9C, Configuration H.



a. SIX - FOOT LEVEL CONTOURS.



b THREE - FOOT LEVEL CONTOURS.

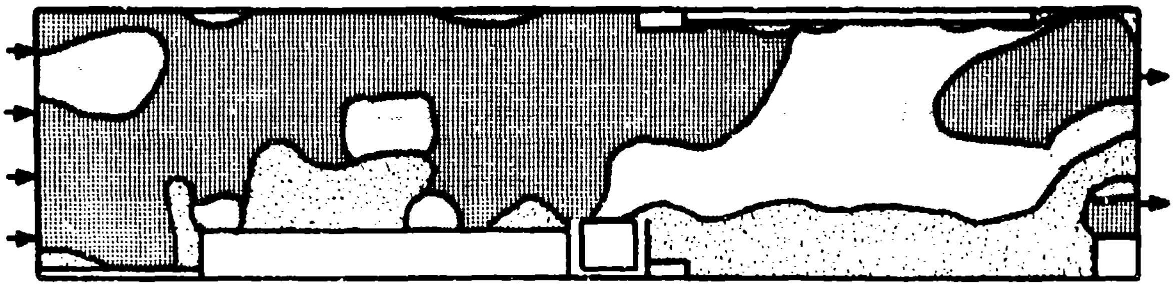
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	90	88
20 - 40 fpm > 40 fpm	10	12

Kearny Pumps (▶) Used: -
PVK Effective Duct Length: -
Outside Wind: SW @ 2.5 mph

Fig. A-20. Airflow Rate Contours for Test Number 9D, Configuration H.

Inlet Doors
10,500 cfm

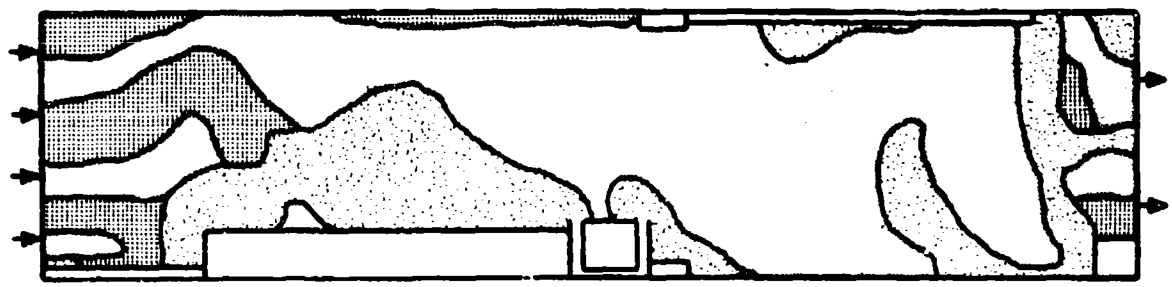
0 PVKs
In Doors



a SIX-FOOT LEVEL CONTOURS.

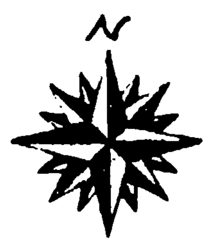
Inlet Doors
10,500 cfm

0 PVKs
In Doors



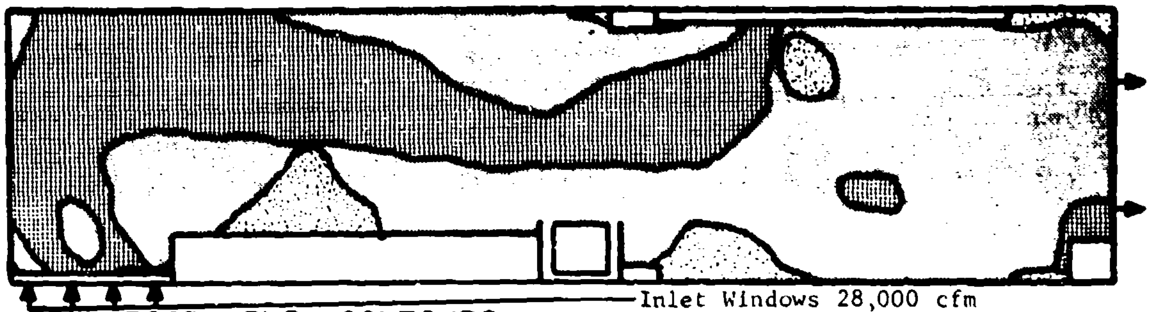
b THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED: 3-Foot Level	PERCENT OF AREA COVERED: 6-Foot Level
< 20 fpm	25	13
20-40 fpm	75	87
> 40 fpm		

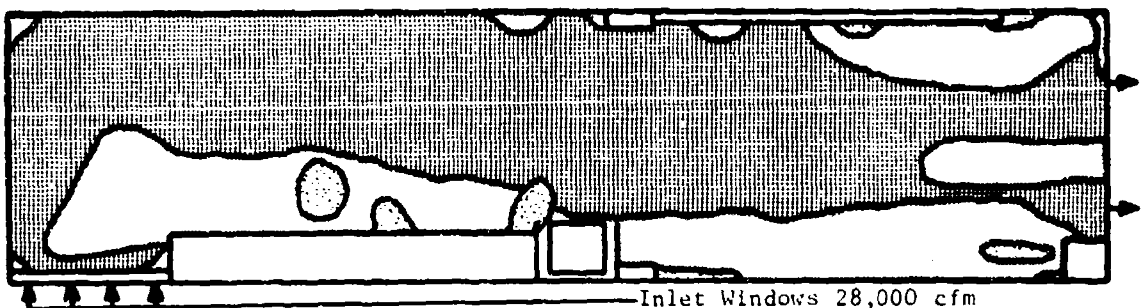


Kearny Pumps (▶) Used: -
PVK Effective Duct Length: -
Outside Wind: SSW @ 3.1 mph

Fig. A-21. Airflow Rate Contours for Test Number 9E, Configuration H.



a. SIX-FOOT LEVEL CONTOURS.



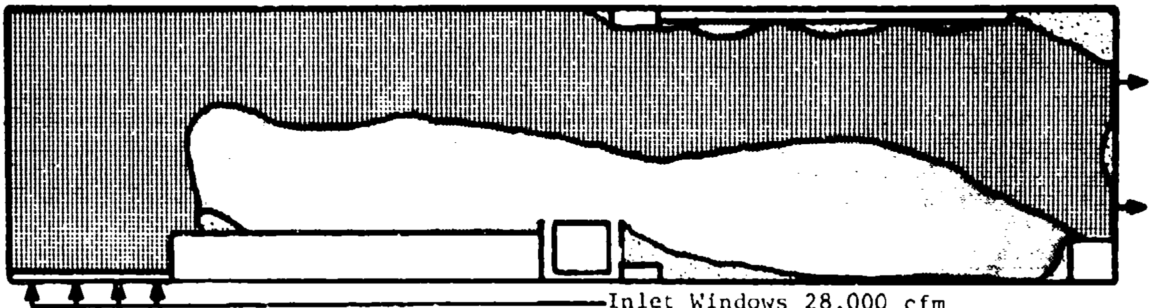
b. THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	4	10
20 - 40 fpm	30	50
> 40 fpm	66	40

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 14 feet
Outside Wind: NNE @ 3.1 mph

Fig. A-22. Airflow Rate Contours for Test Number 4A1, Configuration I.

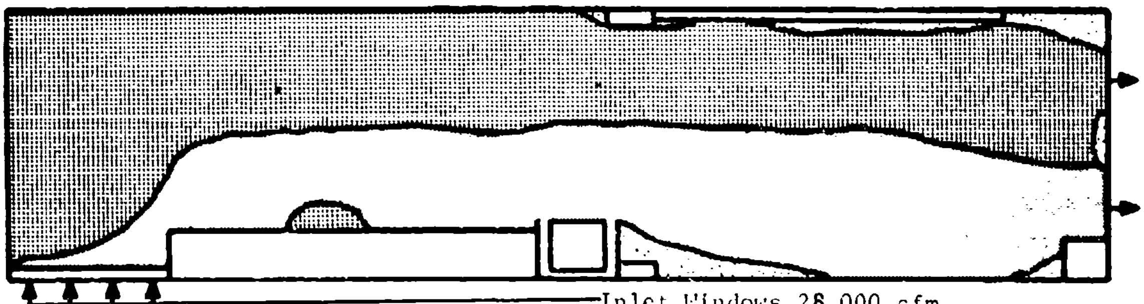
10 PVKs
In Doors



Inlet Windows 28,000 cfm

a. SIX - FOOT LEVEL CONTOURS.

10 PVKs
In Doors



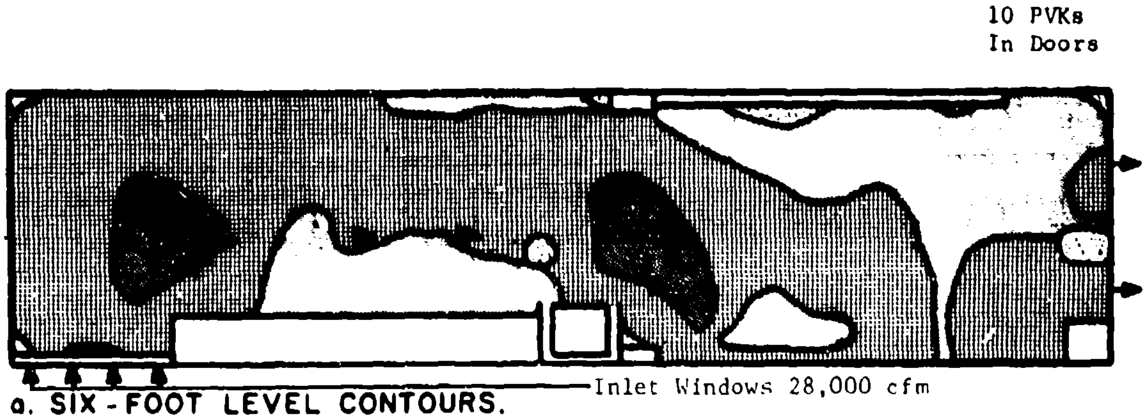
Inlet Windows 28,000 cfm

b THREE - FOOT LEVEL CONTOURS.

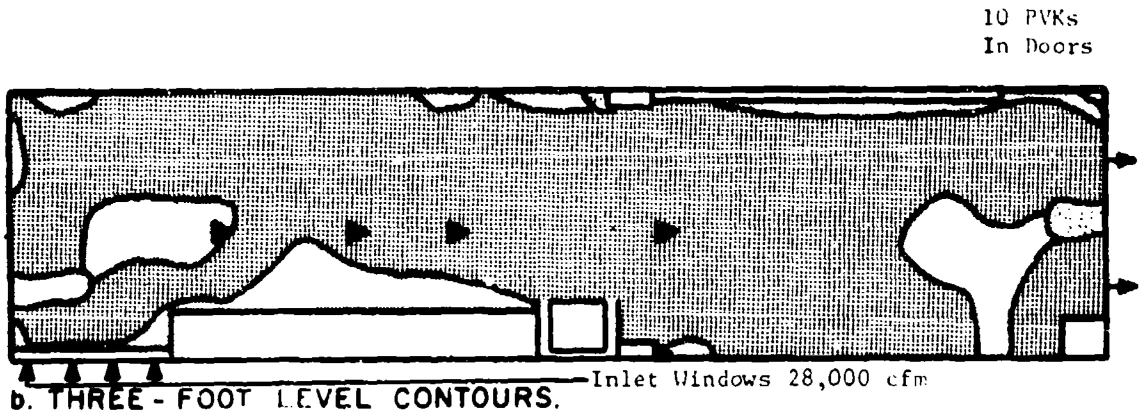
AIRFLOW RATES	PERCENT OF AREA COVERED: 3-Foot Level	PERCENT OF AREA COVERED: 6-Foot Level
< 20 fpm	3	3
20 - 40 fpm	38	30
> 40 fpm	59	67

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: NE @ 2.3 mph

Fig. A-23. Airflow Rate Contours for Test Number 4A2, Configuration I.

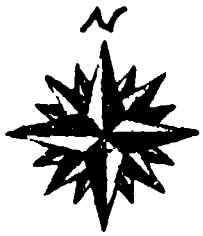


a. SIX - FOOT LEVEL CONTOURS.



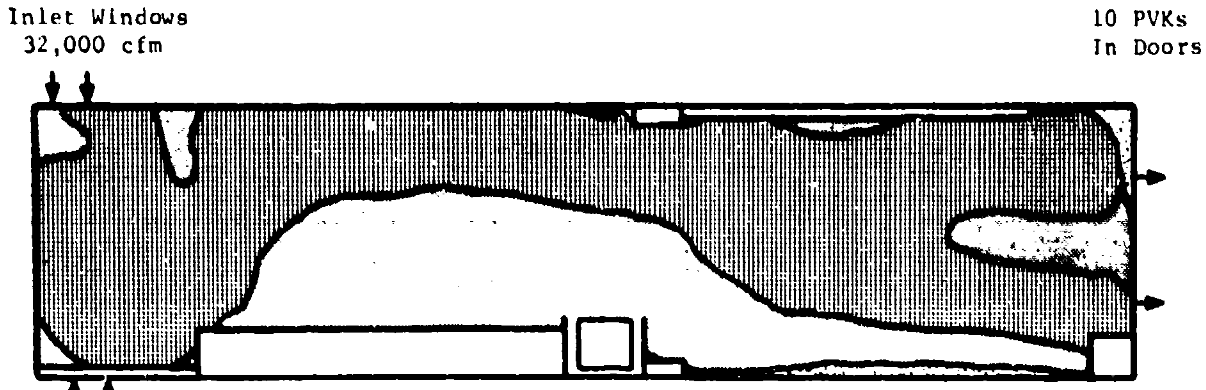
b. THREE - FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	3	2
20 40 fpm	13	30
> 40 fpm	84	68

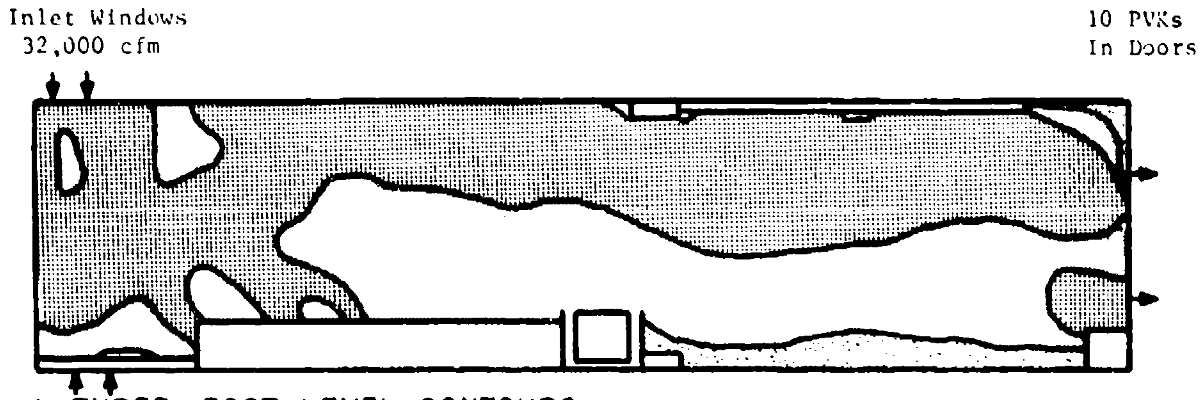


Kearny Pumps (▶) Used: 4
PVK Effective Duct Length: 14 feet
Outside Wind: NNE @ 3.1 mph

Fig. A-24. Airflow Rate Contours for Test Number 4B, Configuration I.

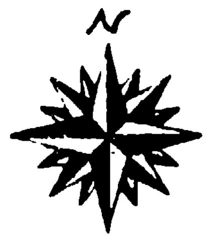


a. SIX-FOOT LEVEL CONTOURS.



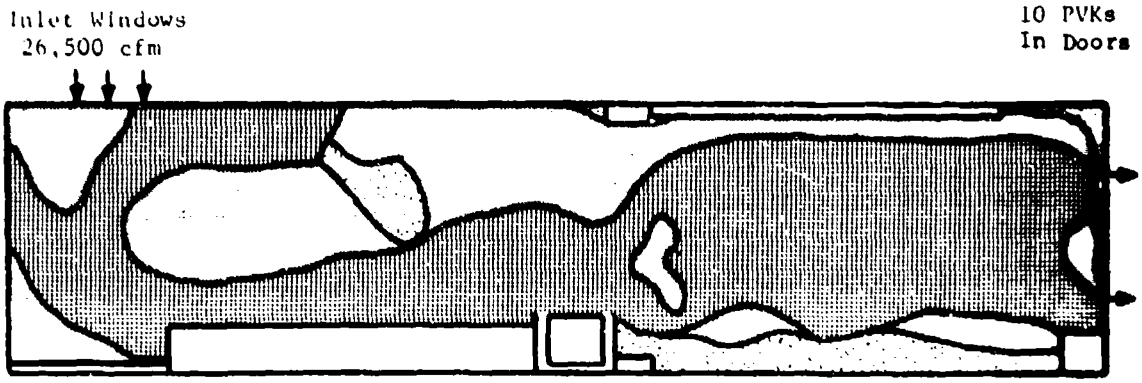
b. THREE-FOOT LEVEL CONTOURS.

	PERCENT OF AREA COVERED	
AIRFLOW RATES	3-Foot Level	6-Foot Level
< 20 fpm	6	3
20-40 fpm	37	29
> 40 fpm	57	68

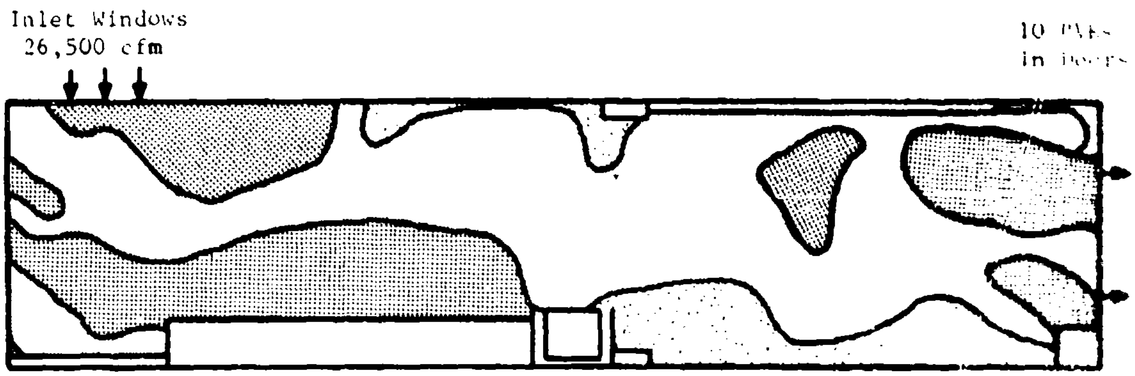


Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: SW @ .74 mph

Fig. A-25. Airflow Rate Contours for Test Number 5, Configuration J.



a. SIX - FOOT LEVEL CONTOURS.

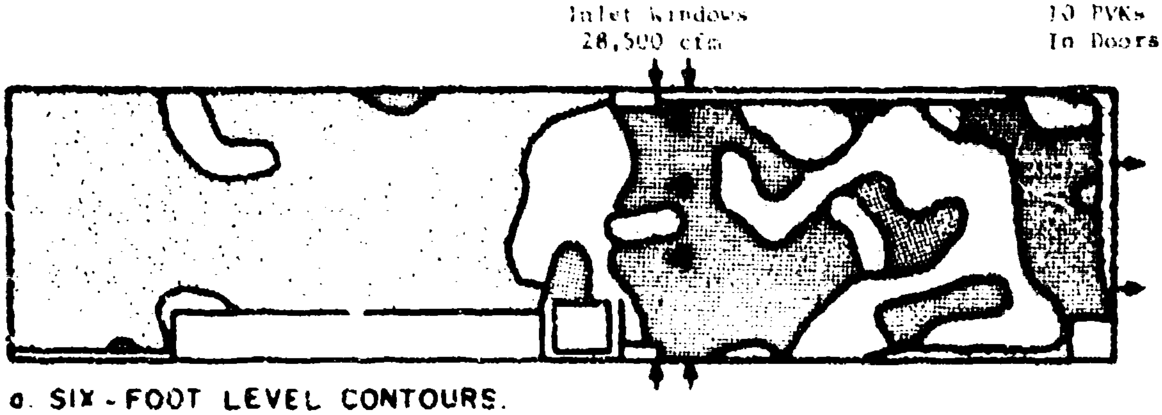


b. THREE - FOOT LEVEL CONTOURS.

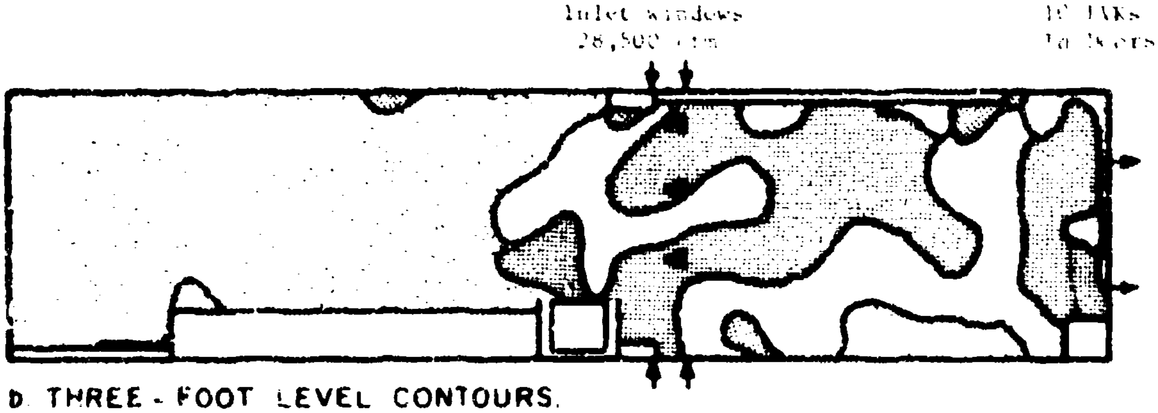
AIRFLOW RATES	PERCENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	24	16
20 - 40 fpm	23	20
> 40 fpm	53	64

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: SW @ 2.0 mph

Fig. A-26. Airflow Rate Contours for Test Number 6,
Configuration K.



a. SIX - FOOT LEVEL CONTOURS.

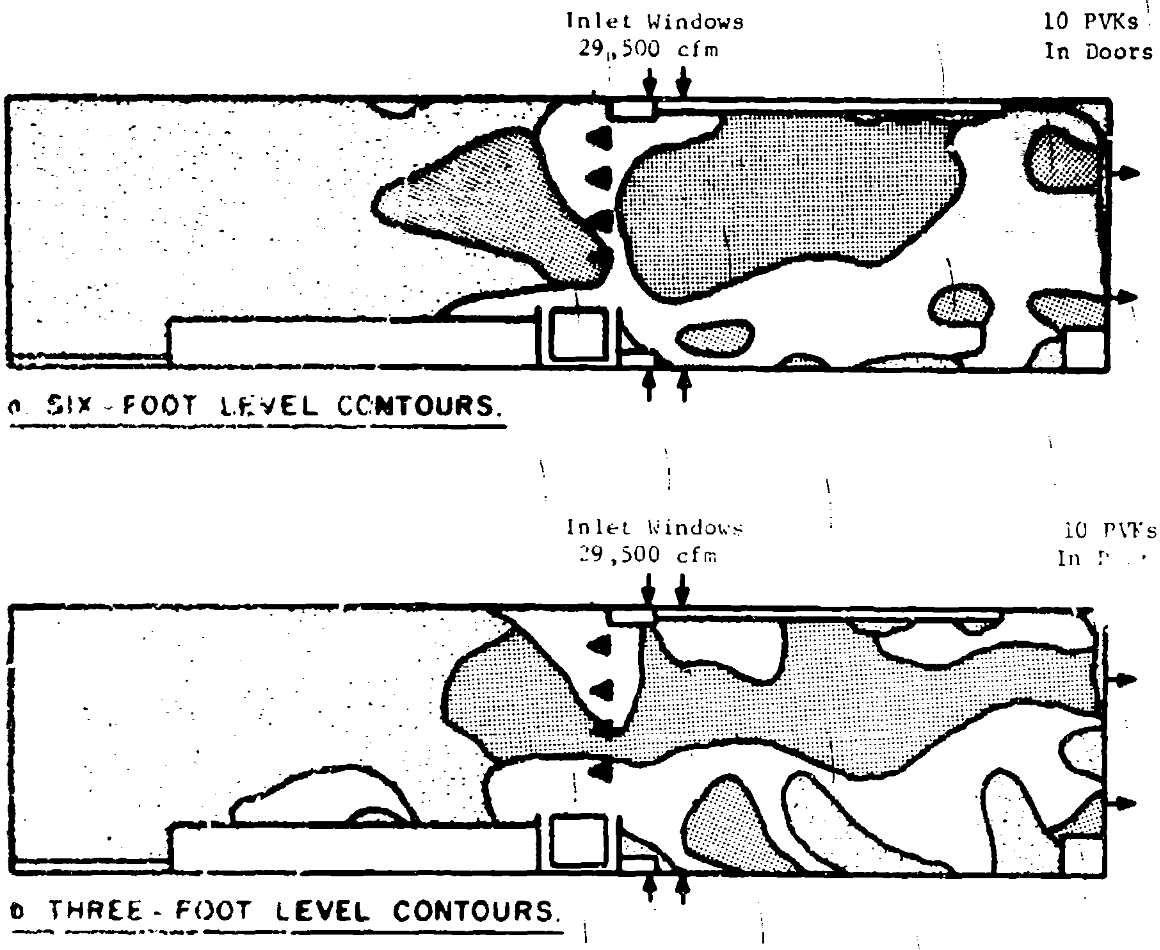


b. THREE - FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED: 3-Foot Level	PERCENT OF AREA COVERED: 6-Foot Level
< 20 fpm	65	55
20 - 40 fpm	16	22
> 40 fpm	17	23

Kearny Pumps (▶) Used: 3
PVK Effective Duct Length: 8 feet
Outside Wind: W 4 .35 mph

Fig. A-27. Airflow Rate Contours for Test Number 8A, Configuration L.



AIRFLOW RATES	PER CENT OF AREA COVERED 3-Foot Level	6-Foot Level
< 20 fpm	55	47
20 - 40 fpm	23	28
> 40 fpm	22	25

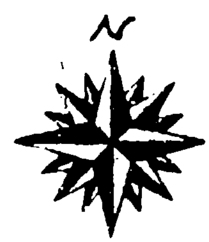
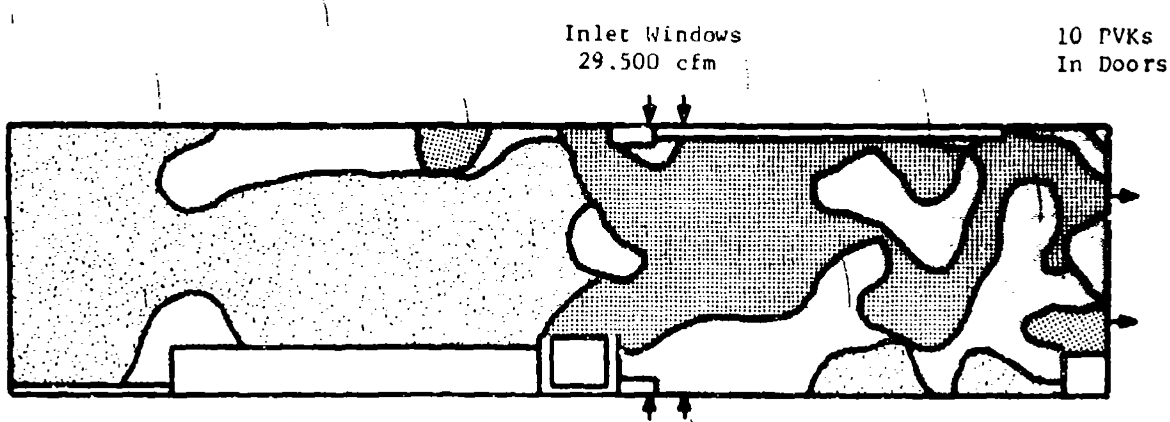
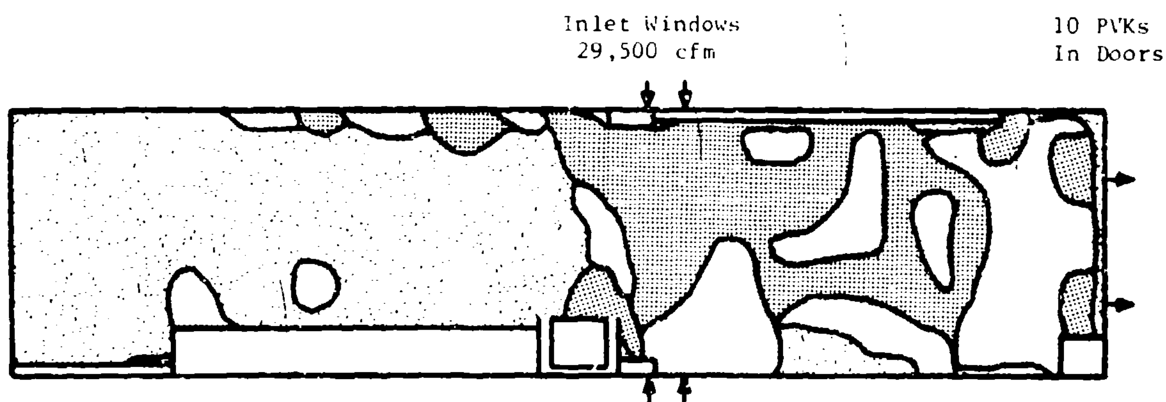


Fig. A-28. Airflow Rate Contours for Test Number 8B, Configuration 1.



a. SIX-FOOT LEVEL CONTOURS.



b. THREE-FOOT LEVEL CONTOURS.

AIRFLOW RATES	PERCENT OF AREA COVERED: 3-Foot Level	6-Foot Level
< 20 fpm	45	37
20-40 fpm	25	18
> 40 fpm	30	45

Kearny Pumps (▶) Used: 0
PVK Effective Duct Length: 8 feet
Outside Wind: SSE @ 1.1 mph

Fig. A-29. Airflow Rate Contours for Test Number 8C, Configuration L.